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Impact of Extremely Low-Frequency Magnetic Fields on Human Postural Control

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Abstract

The general public and workers can be exposed to high-levels of power-line frequency magnetic fields (MFs - up to 10 mT). Although such time-varying MFs have the potential to modulate human postural control, no existing studies have explored MF exposure levels that possibly trigger acute sway responses. This work evaluates time-varying MF exposure (up to 100 mT) in the extremely low frequency range (ELF – up to 300 Hz) and its effects on human postural control. Twenty-two healthy participants were each exposed to randomized, 5-second MF and electric stimulations (0, 50 and 100 mT and 1.5 mA respectively) given at different frequencies (20, 60, 90, 120, and 160 Hz). A force-plate collected participant Center Of Pressure (COP) displacement. Results revealed sway modulations resulting from electric stimulations but not from MF exposures. The mechanical stabilization induced by the inertia of the head-mounted exposure system might have masked acute sway responses.

Keywords

Postural Control, Human, Extremely Low Frequency Magnetic Fields (ELF MF), transcranial Alternating Current Stimulation (tACS)

Co-Authorship Statement

Alicia Allen: Performed all manuscript writing, data analysis, and statistical analysis. Performed majority of data collection process and assisted with computer programming, and experimental design.

Dr. Alexandre Legros: Supervisor, initiated the project and provided industry-matched MITACS funding (industry support from Hydro-Québec, EDF, RTE, NationalGrid/ENA and EPRI associated under the Utilities Threshold Initiative Consortium - UTIC), managed the experimental design and supervised manuscript preparation and review.

Dr. Sebastien Villard: Assisted with data collection, experimental design, statistical analysis and manuscript review.

Michael Corbacio: Assisted with data collection, computer programing, experimental design, and manuscript review.

Dr. Alex Thomas: Advisory committee member, assisted with manuscript review.

Dr. Kevin Shoemaker: Advisory committee member, assisted with manuscript review.

Dr. Michel Guerraz: Advisory committee member, assisted with manuscript review.

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List of Abbreviations

AC	Alternating Current
COP	Centre of Pressure
DC	Direct Current
E-field(s)	Electric field(s)
ELF	Extremely low frequency
EMG	Electromyography
GVS	Galvanic Vestibular Stimulation
ICNIRP	International Commission on Non Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
K _c	Kinocilium
MF(s)	Magnetic Field(s)
MRI	Magnetic Resonance Imaging
SCM	Sternocleidomastoid
SVV	Subjective Visual Vertical
tDCS	Transcranial Direct Current Stimulation
tACS	Transcranial Alternating Current Stimulation
VOR	Vestibulo-Ocular Reflex
VSR	Vestibulospinal Reflex
WHO	World Health Organization

Chapter 1

1 General introduction

Even though we cannot see them, magnetic fields (MFs) are a part of our everyday lives. Humans are exposed to both natural and manmade MF sources on a daily basis. In the following sections, we will explore sources of MFs in our daily environment and possible interactions of these fields with human body. More specifically, it has been reported that the vestibular system is particularly sensitive to MF exposures, including both static and time-varying MFs (Glover, Cavin, Qian, Bowtell, & Gowland, 2007; L. E. van Nierop, Slottje, Kingma, & Kromhout, 2013). Therefore, we are interested in exploring the functional consequences of a time-varying MF on the vestibular system through the investigation of one of its main outcomes: postural control. An overview of the vestibular system's anatomy, physiology and main functions will be given, along with vestibular dysfunctions and commonly used methods for evaluating vestibular system functioning. Then, we will review the literature on the effects of static and time-varying MF exposures, the second of which has the property to induce electric fields (E-fields) and currents in biological structures. Next, the literature on the effects of electric current stimulation applied to the human vestibular system will be reviewed, followed by an overview of the possible mechanisms of action involved.

1.1 Magnetic fields and possible human body interactions

MFs can be produced by a magnet or by moving electric charges. These fields can either be static, such as those produced by a direct current (DC) source, or time-varying, produced by an alternating current (AC) source. A static MF will have a constant value over time, whereas a time-varying MF will have a changing value over time. Time-varying MFs are sub-classified into extremely low frequency (ELF, <300 Hz), low to medium frequency (300 Hz – 3 MHz), and high frequency (3 MHz – 300 GHz) MFs. For the purpose of this research, we will be focusing specifically on ELF MFs, such as those produced by power-lines (i.e. 50 and 60 Hz).

The intensity (H) of a MF is measured in amperes per meter (A/m), however it is commonly expressed in terms of magnetic flux density (B), which is measured in Tesla (T), millitesla (mT, i.e. 10^{-3} T), or microtesla (μ T, i.e. 10^{-6} T). The MF intensity and flux density are related by the equation: $B = \mu \cdot H$ where μ is a permeability constant (in free space, $\mu = 1.256 \times 10^{-6}$

⁶). MF values are proportional to current intensity (I) and the distance (r) from the source by the following equation: $B = (\mu \cdot I) / (2 \cdot \pi \cdot r)$. Therefore, MF values decrease quickly with increased distance from the source. This equation is used to calculate the flux density at a given distance r from the source (from an electric wire). For example, it can be used to calculate the flux density level produced by a power-line when standing 4 meters below it.

Time-varying MFs have the ability to induce electric fields (E-fields) and currents (expressed in terms of current density noted J). E-fields and induced current density are related by the following equation: $E = J / s$. The s value refers to conductivity, which is the capability of a material to conduct electricity; it is expressed in Siemens per meter (S/m). Figure 1 shows a visual representation of induced fields and currents created by a time-varying MF resulting from an AC source, such as a power line. Induced current density values are related to the conductivity of the material (s), the distance from the MF source (r), the MF value (B), and the MF frequency (f) as shown by the following equation (example of an AC current circulating in a wire): $J = s \cdot \pi \cdot r \cdot f \cdot B$. This formula can be used to calculate induced current density in a sphere of radius r of conductivity s by a time-varying MF of a given flux density (B) at frequency f.

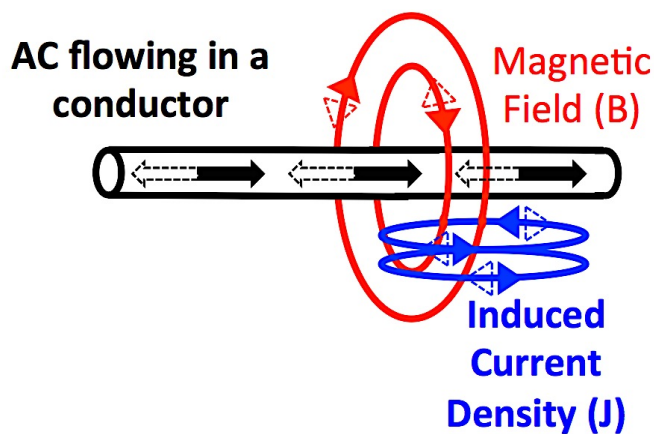


Figure 1: MF-induced current density produced by an AC.

Interestingly, the human body itself acts as a conductor, with different tissues having different conductivities. For example, the conductivity of cerebral spinal fluid is ~2.0 S/m, blood is ~0.7 S/m, bone ~0.02 (compact bone), and the brain ~0.07 S/m (Gandhi, Kang, Wu, & Lazzi, 2001). Therefore time-varying MFs have the ability to produce induced electric fields and currents within the human body. These have the potential to interfere with biological processes,

possibly causing a depolarization or hyperpolarization of the cell and therefore modulating transmitted neuronal signal. These potential interactions are discussed further in section 1.9.

1.2 Magnetic field sources in our daily environment

The main natural MF source is the Earth's geomagnetic field. Manmade MFs result from electricity generation and distribution among other industrial processes. The Earth's naturally produced geomagnetic field is mostly static (and cannot therefore elicit induced fields and currents in conductors or biological systems), reaching values at Earth's surface of 35-70 μT (0.035-0.07 mT) according to the World Health Organization (WHO, 2006). Manmade MFs can be static, such as MRIs (up to 11 T or 11,000 mT) or time-varying, such as those produced by power-lines.

Average residential power-frequency MFs are 0.07 μT in Europe (50 Hz) and 0.11 μT in North America (60 Hz) (WHO, 2007). When considering average exposure levels for the general public including both residential and rural areas, the value is 0.1 μT at power-line frequencies according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 2010). Additional information presented by the New Zealand Ministry of Health (2013) showed that MF values inside a house or office reached 0.05 – 0.15 μT . These values can rise when near a switchboard (1.0 – 3.0 μT , measured at a 300 mm distance from the source) or when standing directly under power lines, reaching values of 20 μT for 225 kV power lines and 30 μT for 400 kV power lines (Lambrozo, 2013).

Considering electrical household appliances, mean MF exposure levels are highest among microwave ovens ($> 0.6 \mu\text{T}$, at 2.45 GHz), coffee grinders ($> 0.6 \mu\text{T}$), electric shavers (0.3 μT), and electric hair dryers (0.3 μT) (Mezei et al., 2001). These MF values are based on measurements using a portable device. Higher MF values can be found when measurements are taken closer to the MF source. For example, when measuring at a distance of 3 cm from the source, exposure levels can reach up to 2 mT when using hair dryers (Gauger, 1985), electric hair clippers (Gandhi et al., 2001), electric shavers and electric drills (Lambrozo, 2013).

For some occupations, such as power-line workers, exposure levels can be much higher than the general public, depending on the type of work involved. The WHO (2007) has identified that occupations including power line workers, industrial welders, and electricians can experience average exposure levels during the work day greater than 3 μT , which is 30 times

higher than average exposure levels for the general public. Gandhi et al. (2001) have identified exposure levels of above 1 mT for power line operators and for those working closely with high current conductors, such as live-line electric utility workers, exposure levels can reach up to 10 mT (WHO, 2007). With many humans being exposed to ELF MF sources in their everyday lives, it is important to consider potential interactions MFs could have on our biology and behavior.

1.3 Best known acute effect of MF on humans

With workers and citizens being exposed to MFs daily, several organizations, such as the WHO, the Institute of Electrical and Electronics Engineers (IEEE), and the ICNIRP, are working at providing comprehensive reviews of the literature and establishing health and safety guidelines for human MF exposure (Gowland & Glover, 2014; ICNIRP, 1998; IEEE, 2002; WHO, 2007). The WHO continues to encourage research on the health effects of MFs on humans through its international EMF project, initiated in 1996, as data is still needed to further establish safe international exposure. In order to inform the safety exposure guidelines, these organizations use evidence from the most well-established acute biological effect of induced electric fields in human tissue to date: magnetophosphene perception (ICNIRP, 2010).

Magnetophosphenes are a flickering visual perception instantaneously occurring when one is exposed to a sufficiently strong time-varying MF. These flickering perceptions were first reported in 1896 (d'Arsonval, 1896) and have been investigated since then in terms of determining a threshold for observed effects. Uncertainty on this threshold for an acute response still remains. The reference study in the domain is from 1980 and it reports a lowest threshold for magnetophosphene perception at 8.1 mT in the dark for a MF stimulus delivered at 20 Hz (Lovsund, Oberg, Nilsson, & Reuter, 1980). Increasing the frequency of the signal increases the required flux density to reach the perception threshold. This frequency-response dynamic, which still remains to be clarified, is currently interrogated in a current project from our group (Souques et al., 2014). This frequency-dependent effect shows the importance of considering not only the MF level alone but also the frequency of the MF when exploring threshold effects for biological responses. It is suggested that this perception is due to the modulation of rod cells membrane potential in the retina. Due to their specific properties including a sensitivity to weak membrane

depolarization, on the order of 0.6 to 200 μV (Attwell, 2003), they could be the most responsive targets for such exposures.

Interestingly, retinal rod cells share many physiological and functional similarities with vestibular hair cells as both cells use graded potentials for signal processing (Juusola, French, Uusitalo, & Weckstrom, 1996). Graded potentials indicate continuous variations in resting membrane potentials, as opposed to the characteristic all-or-none action potential. Vestibular hair cells are the functional units of the human vestibular system, which is responsible for maintaining balance. Due to the aforementioned similarity between retinal rod cells and vestibular hair cells, there is the possibility that vestibular system functioning could also be affected by power-line frequency MFs.

1.4 Vestibular anatomy, physiology, and function

1.4.1 Vestibular anatomy

The vestibular system, responsible for gaze control and maintaining balance, is located in the inner ear (one on each side of the head). It is located approximately 2.5 cm from the beginning of the external auditory canal and is approximately 2 cm long, about the size of a dime (James Byron Snow, 2009; Tortora & Nielsen, 2012). Its main structure consists of a series of membranous tubules filled with endolymph fluid (the labyrinth), which is continuous with the auditory component of the inner ear, known as the cochlea.

There are two main components of the vestibular system: the semicircular canals and the otolith organs. Each of the three semicircular canals are perpendicular to each other and are responsible for detecting a specific angular acceleration corresponding to pitch, yaw, and roll movements of the head. The otolith organs, the utricle and saccule, are responsible for detecting horizontal and vertical linear acceleration of the head, respectively. A localized dilation, known as the ampulla, is situated at the end of each semicircular canal duct.

1.4.2 Vestibular physiology

The integration of information from the vestibular system in both inner ears indicates the acceleration of the head. These accelerations are detected differently considering the semicircular canals and the otolith organs. In the semicircular canals, a shift in the endolymph fluid movement (due to head tilting) will cause the sensory cells called hair cells (housed within the

cupula) to bend and either depolarize or hyperpolarize depending on the direction of fluid movement and hair cell orientation. Hair cells in the semicircular canal are oriented so that the tallest cilium, known as the Kinocilium (K_C), is closest to the ampulla (Figure 2). This causes increased or decreased firing rates of the afferent nerves on which the hair cells synapse. The otolith organs behave in a similar fashion. The difference is the use of shifting otoconia (calcium carbonate crystals) located in the otolith membrane to stimulate the hair cells and detect movements instead of endolymph fluid movement (Figure 3). The hair cells in the otolith organs are oriented relative to the striola, with the K_C closest to the striola.

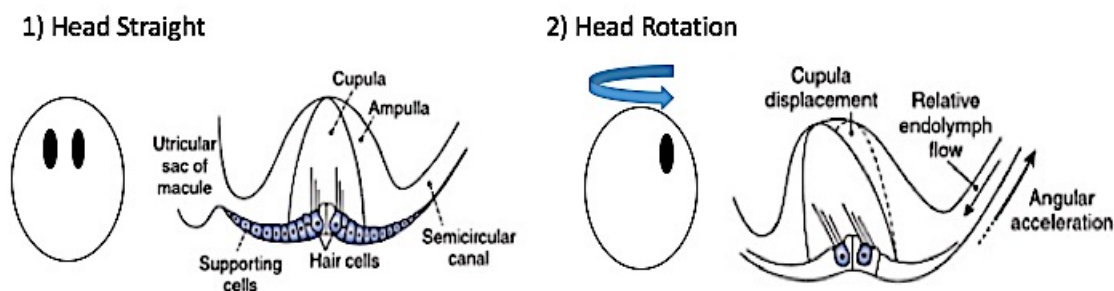


Figure 2: Hair cell movement detection in the semicircular canals. Figure adapted by author from Baloh et al. (2011). The adaptation of this graphic is by permission of the copyright holder: Oxford University Press ©.

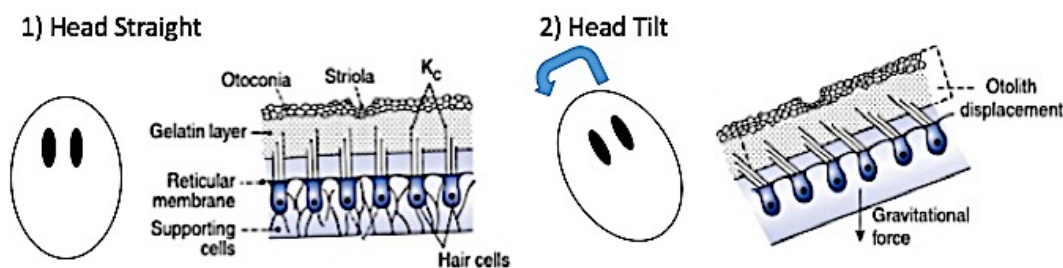


Figure 3: Hair cell movement detection in the otolith organs. Figure adapted by author from Baloh et al. (2011). The adaptation of this graphic is by permission of the copyright holder: Oxford University Press ©.

A commonality between the semicircular canals and the otoliths is that both structures use hair cells to detect accelerations. There are two types of hair cells in the vestibular system known as type 1 cells and type 2 cells (Figure 4). Each type of hair cell synapses onto a different

afferent nerve: type 1 onto irregular afferents and type 2 onto regular afferents, both of which carry signals to the vestibular nuclei. The details of each specific type of cell are still unclear apart from their differences in shape and number of synapses. However, it is known that regular afferent nerves make up 75% of vestibular afferents (Baird, Desmadryl, Fernandez, & Goldberg, 1988; Goldberg, 2000; Highstein, Goldberg, Moschovakis, & Fernandez, 1987).

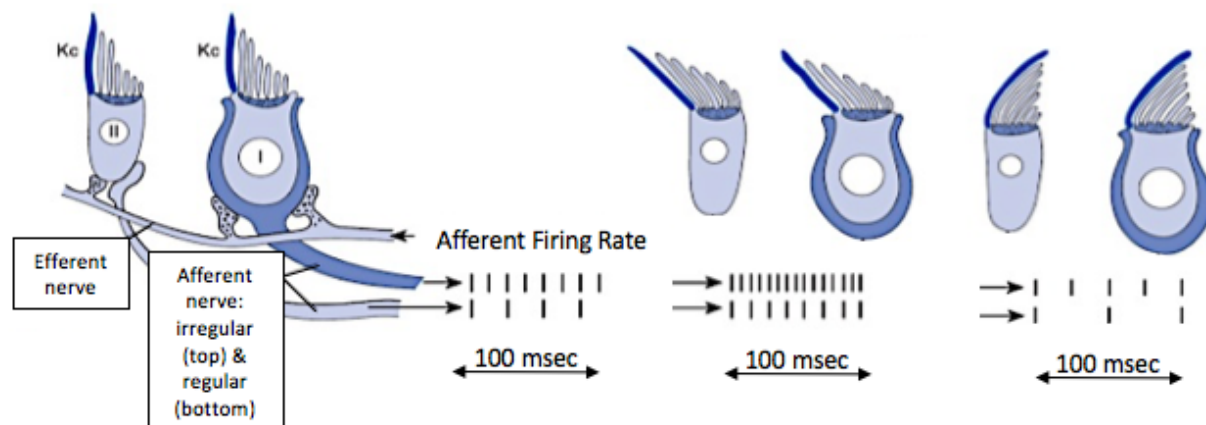


Figure 4: Vestibular hair cells and subsequent changes in firing rate when depolarized or hyperpolarized. Figure adapted by author from Baloh et al. (2011). The adaptation of this graphic is by permission of the copyright holder: Oxford University Press ©.

1.4.3 Vestibular function

The vestibular system is responsible for two main functions organized around two reflex loops: the vestibulo-ocular reflex (VOR) and the vestibulo-spinal reflex (VSR). Both reflexes together, in combination with visual, proprioceptive, and auditory information, globally control overall postural stability.

The VOR acts to stimulate certain muscles that control eye movements in response to head movements in order to stabilize images in our surrounding. This involuntary reflex allows us to perceive the world around us clearly even if we are moving. The VOR uses the semicircular canals and the otolith organs to detect and correct for head accelerations.

The second main function of the human vestibular system is to maintain and manage the position of the head with respect to the rest of the body through the VSR. The VSR acts to stimulate appropriate extensor and flexor skeletal muscles below the neck through signals

transmitted via the vestibule-spinal tracts to the spinal cord. Activation or inhibition of appropriate muscles will ultimately stabilize the body in response to a head tilt movement.

1.5 Vestibular diagnostic tests and disorders

There are many diagnostic tests used to stimulate the vestibular system and thereby test its functioning. Many physicians can achieve a better understanding of vestibular functioning by analyzing the two main reflex loops previously mentioned: VOR and VSR (Lang & McConn Walsh, 2010). Each of these loops can be assessed by first stimulating the vestibular system using different clinical tests and then analyzing selected variables to assess vestibular performance. We will cover the common variables assessed in each of the main clinical tests in this section, followed by a brief explanation of common vestibular disorders.

The first relatively simple diagnostic test is known as the Halmagyi test, which involves instructing the patient to fixate their eyes on a target directly in front of them while rapidly turning their head from side to side (in a yaw movement). This triggers the VOR for assessment. An individual with a compromised vestibular system would have difficulty fixating their gaze while rapidly moving their head. Similarly, the Rotary Chair test can also be used to assess the VOR, using a rotating chair instead of self-directed head movements to trigger the VOR. The VOR should be tested at low frequencies (0.5-5 Hz) using an active, voluntary, freely moving head rather than a rotating chair test in order to simulate natural activities (Dieterich & Brandt, 1995).

Another test exploring the VOR is known as the caloric reflex test. This test involves irrigation of warm or cool liquid through the external auditory canal and can specifically test for functioning of the nearby horizontal semicircular canal. The resulting temperature change in the external auditory canal induces convection currents in the nearby horizontal semicircular canal, which should induce an artificial perception of yaw rotational acceleration. Absence of resulting eye movement compensations due to VOR indicates weakness of the horizontal semicircular canal on the side of the head that is being irrigated (Goncalves, Felipe, & Lima, 2008).

Apart from VOR testing, there are some tests exploring the VSR. The main test is the sacculo-collic test, also known as the vestibular-evoked myogenic potential (VEMP) test. This test uses intense auditory clicks (delivered with headphones) to stimulate the otoliths, specifically the saccule. The reflexive action is a sternocleidomastoid muscle contraction

ipsilateral to the side of the head experiencing the auditory clicks (Bath, Harris, & Yardley, 1998). VEMP testing is a useful diagnostic test for peripheral and central vestibulopathies (Roceanu, Schoenen, De Pasqua, & Bajenaru, 2010). A study by Welgampola and Colebatch (2005) found that assessing the VEMP in response to auditory clicks is the current best fit for the role of an otolith function screening test. Similarly, the head drop test can test for VSR functioning. This test is performed by having a patient lie down with their head suspended about 10 cm above a cushioned surface and allowing it to drop down. Responses of the neck muscles to this motion will determine the functionality of the VSR (Ito et al., 1995).

All of the previously mentioned diagnostic tests aim to stimulate the vestibular system in some way. We will now cover the variables that are analyzed during these tests. First, the variable assessed for VOR testing is nystagmus, a rapid vertical or horizontal eye movement. This can be recorded using electronystagmography, which uses electrodes placed around the eye to record eye movements or videonystagmography, which uses an infrared camera to track eye movements. In terms of the VSR testing, the variable recorded here is electromyographic (EMG) activity in the neck muscles, specifically the sternocleidomastoid muscle. Another variable that can be tested is known as the Subjective Visual Vertical (SVV). This is a measure of what patients perceive to be a true vertical compared to actual vertical. SVV can be used to specifically analyze the functioning of the utricle (Lang & McConn Walsh, 2010). Finally, posturography describes the recording of patient standing balance patterns (postural control) using a force platform. The force platform will measure center of pressure (COP) movements, which can be further analyzed for an overall stability assessment.

The aforementioned techniques are used clinically to diagnose vestibular disorders. These disorders typically present themselves with symptoms of vertigo or imbalance. Pathologies that can result in vestibular compromise include labyrinthitis, vestibular neuritis, Meniere's disease, and endolymph hydrops to name a few. To diagnose the specific cause of vertigo and whether it is vestibular in origin, use of the previously mentioned diagnostic tests is key to locate the specific structure being disrupted. Apart from vestibular disorders, there are other sources of stimulation that can effect vestibular functioning. These are presented in the following sections.

1.6 The vestibular system and electric stimulation

The previous section explored manipulation of the human vestibular system for the purpose of diagnostic testing and different variables that can be used to assess vestibular functioning. Interestingly, there is a specific type of electric stimulation using a direct current (DC) that targets the vestibular system, known as galvanic vestibular stimulation (GVS). GVS has been used in diagnostic testing and is known to reliably produce a loss of balance in humans. GVS therefore serves as a useful comparison point when studying the effects of MFs on postural control and so we will explore it further in the following section.

1.6.1 Transcranial Direct Current Stimulation (tDCS) – Galvanic Vestibular Stimulation (GVS)

tDCS consists of delivering an electrical signal to the head using 2 or more skin electrodes (an anode and a cathode). When this technique is applied to the vestibular system, it is called galvanic stimulation. More specifically, galvanic stimulation consists of a non-invasive DC stimulation of the vestibular system (GVS) with electric currents on the order of 1 to 2 mA. This can result in spectacular changes in postural control and balance. The typical observed effect of GVS exposure in healthy participants is a body tilt towards one side occurring 1-2 seconds after the onset of the stimulation (Inglis, Shupert, Hlavacka, & Horak, 1995). Measurement of the displacement of the COP using a tracked marker placed on the head while exposed to GVS reveals an increase of the total length of the displacement of the COP over a given period of time (called path length) (Day, Severac Cauquil, Bartolomei, Pastor, & Lyon, 1997). A study using sway recordings from a force plate over a period of 5 s revealed peak COP displacements up to 4.5 cm laterally from the center of pressure (Yang et al., 2015). They also found a threshold of GVS exposure producing an acute postural control response to be 0.32 mA.

In terms of mechanisms of action for observed GVS effects, Fitzpatrick & Day (2004) provide one of the most thorough investigations found in the literature. They used a detailed anatomy and electrophysiology analysis of the semicircular canals and otoliths in order to explain observed GVS balance responses, using vector summation. They found that GVS responses affect both the otolith organ and semicircular canals through induced currents. Specifically, the effects are thought to bypass the hair cells and instead target the afferent neurons that the hair cells synapse onto. GVS will therefore affect the vestibular afferents

regardless of the hair cell orientation. This is different to natural movements, which would typically affect the hair cell orientation and then translate that signal onto the afferent nerves. Interestingly, regular afferent neurons are only minimally affected by GVS and it is the irregular afferent neurons that are largely affected. This signal from the vestibular afferents of the semicircular canals signals a large roll and small yaw movement directed away from the stimulation anode electrode. The signal from the vestibular afferents of the otoliths signals a linear acceleration away from the anode. The typical observed tilt response directed towards the anode is due to the VSR compensating for these perceived movements.

Now that we have overviewed the suspected mechanism of action behind the GVS response being due to induced currents, it is important to consider what levels of current exposure are reaching the human vestibular system with different GVS current levels. Nadeem et al. (2003) predicted that a 100 mA/m^2 current density can be induced in brain tissue near the inner ear (3 cm deep from the external part of the head model) with a 1 mA current. Miranda et al. (2006) modeled the current distribution of tDCS using a 2.0 mA exposure. It was concluded that maximum values of 100 mA/m^2 , corresponding to a 0.22 V/m electric field, could be obtained at levels 3.5 cm below the scalp. Salvador et al. (2012) studied the effects of tissue dielectric properties on the electric field produced by tDCS using a head model. This study highlighted the importance of taking appropriate conductivities of different regions in the head when calculating the induced electric fields produced by tDCS. This highlights the complexities of predicting the exact induced electric fields produced in the human head using modeling studies. In terms of the level of the vestibular system, numerous different fluids and structures with different conductivities must be considered, complicating the induced electric field prediction process.

1.6.2 Transcranial alternating current stimulation (tACS)

While GVS exposes the human vestibular system to a direct current (up to 2 mA), tACS stimulates using an alternating current (Zaghi, Acar, Hultgren, Boggio, & Fregni, 2010). tACS applied to the vestibular system has not been studied as much compared to GVS and there have been no studies to date that test the effects of high frequency tACS on human postural control or human vestibular responses. However, tACS effects have been explored in other areas of the brain. Some research on proposed mechanisms of action for tACS in the brain suggests the

possibility of the tACS stimulation interrupting the ongoing oscillations in the brain. This possibly achieved by inducing synchronizing changes in brain activity, modulating synaptic vesicle release, or by changing the level of electrical noise (Zaghi et al., 2010).

A rat study (Jensen & Durand, 2007) showed that applying high frequency (50-200 Hz) sinusoidal waves using AC stimulation could disrupt cell axon communication activity and this effect is dependent on the amplitude and frequency of the stimulus, not the stimulus duration. Kanai et al. (2010) explored cortical excitability by delivering tACS to the human occipital cortical region of the brain (at frequencies of 5, 10, 20, and 40 Hz) and reported the perception of phosphenes, a flickering visual phenomenon explained previously in section 1.3. They found that the 20 Hz frequency condition increased visual cortex excitability as indicated by the reported phosphene threshold. They proposed that tACS modulation of cortical excitability is frequency-dependent and that phosphenes are created due to tACS interaction with the visual cortex, not the retina. This is interesting since magnetophosphenes produced by time-varying MFs are thought to be due to induced electric fields with retinal rod cells, suggesting that the mechanism of action for tACS and MF exposure differs (Attwell, 2003). However, this hypothesis has been proven wrong in a study confirming that the effects observed by Kanai were actually resulting from a retinal stimulation (Laakso & Hirata, 2012).

To study tACS exposure effects on the human vestibular system, it is important to consider the current density distribution in the brain through a review of modeling studies. When considering the current density values reaching the thalamus (the deepest portion of the brain), a maximum current density of 50 mA/m^2 can be reached using a 1 mA stimulus applied to electrodes placed behind the ear (Ferdjallah, Bostick, & Barr, 1996). This corresponds to an electric field value of 0.15 V/m. Induced electric fields reach maximal values (0.198 V/m using a 1.12 mA tACS exposure) just beneath the electrode surface (Merlet et al., 2013). No modeling studies have been found regarding tACS induced current and electric field values at the level of the vestibular system.

1.7 The vestibular system and static magnetic field exposure

There have been many studies that have found an association between MRIs and vertigo, nausea, nystagmus, and standing balance (see Table 1 for summary). We will start with an overview of static MF studies (using MRIs) for clarification purposes since several studies mentioned later

combine static MF and time-varying MFs (Glover et al., 2007; L. E. van Nierop et al., 2013; L. E. van Nierop, Slottje, van Zandvoort, de Vocht, & Kromhout, 2012). The following selected studies are presented in order of the variable studied. We will first present studies of postural control responses followed by studies of nystagmus.

Theysohn et al. (2014) studied vestibular effects of a 7 T MRI (7,000 mT for comparison) compared to 1,500 mT and 0 mT in healthy volunteers. 46 healthy participants were recruited and exposed for 30 minutes to static MFs. Postural control recordings using a force plate were taken at 3 different time intervals (before exposure, 2 minutes after and 15 minutes after exposure). Their results showed a significant increase in the average size of oscillations (quantified using mean sway path and sway path length characteristics) at the 2-minute post-exposure mark (compared to the pre-exposure period). This normalized back to pre-exposure values at the 15-minute post-exposure mark. They surmised that these changes are attributed to the vestibular system since proprioceptive feedback was minimized during the experiment and conditions with the eyes opened showed suppressed effects.

Glover et al. (2007) investigated several aspects of static MF exposure and how they affected vestibular system functioning, using a 7 T MRI. They studied vertigo with respect to static, pulsed, and time-varying MF. The latter two results will be discussed in the following sections. For the static MF condition, participants were asked to stand either close to ($B = 800$ mT) or further from ($B = 200$ mT) the MRI while sway movements were tracked using a video camera. In 3 of 10 participants a significant mean forward displacement was found in the near position compared to the far position. Two of the subjects perceived a falling sensation in the near position, a description consistent with vertigo as commonly described in clinical settings. It should be noted that the experience of vertigo is linked to the vestibular system since vertigo is described as a perception of motion in the absence of actual mechanical motion and perception of motion occurs at the level of the vestibular system. Vertigo could also arise from an inconsistency between visual input and actual mechanical motion. Similarly, there is a clear vestibular pathway for nausea and vomiting (Horn, 2008). Some studies have used the basis of this pathway as an outcome to measure vestibular functioning in MRI studies. Such studies will be presented in the following section.

Roberts et al. (2011) studied nystagmus in participants while they were exposed to a static MF (3 and 7 T) produced by an MRI. Nystagmus was continuously monitored using

infrared video recording from when the participant entered the MRI bore to when they exited. Ten participants with normal labyrinthine function were tested along with two participants with no labyrinthine function. Normal labyrinthine function is defined as having an intact and functional labyrinth. It was confirmed that labyrinthine function was necessary to induce nystagmus as healthy subjects developed a robust nystagmus while in the MRI and participants with no labyrinthine function did not. For healthy participants, the magnitude of the induced nystagmus was dependent on the strength of the time-varying MF (induced by movement through the static MF), implying that stronger time-varying MFs that are induced by movement through the static MFs have a stronger effect on the vestibular system, particularly the VOR.

Mian et al. (2013) exposed 25 participants to a static MF produced by a 7 T MRI while recording eye movement patterns and reported sensations of motion. All participants had clear nystagmus while being pushed into the MRI. Values peaked shortly after arriving in the MRI and slightly declined over time spent in the MRI. This is interesting since movement within a static MF is considered a time-varying MF. Therefore, as the participants are being moved into the MRI while the static MF is present with a gradient, they are being exposed to a time-varying MF. Additionally, 24 of the 25 participants reported perceptions of motion (or vertigo). They also discovered that the onset of the perception of motion (~ 5.1 T) occurred at a significantly higher field strength than nystagmus onset (~ 1.7 T). The results of this study involving static MF evoked perception of motion is in line with the MF evoked nystagmus observed by the normal patient group of the Roberts et al. (2011) study.

Considering these studies, we can see that static MFs produced by MRIs as well as time-varying MFs (induced by movement through a static MRI MF) have the ability to induce nystagmus and postural control alterations. We were also introduced to the idea of a time-varying MF being produced with movement through a static MF. Observed nystagmus effects in healthy volunteers are still persistent here according to Mian et al. (2013). This introduces the idea that time-varying MFs could potentially affect vestibular functioning. Some studies investigating this idea use induced time-varying MFs through head movements within the static MF of an MRI. The following section summarizes the few studies previously conducted that study the effects of these time-varying MFs on the human vestibular system. These studies use analysis of postural control, nystagmus, and subjective reports of vertigo sensations.

1.8 The vestibular system and time-varying magnetic fields

The impact of research on the effects of ELF MFs on the human vestibular system has been limited to date due to the difficulty in reproducing experimental results and the diversity of exposure protocols used. This makes it difficult to compare the results from different studies (see Table 1 for summary). The results of these studies will be discussed below.

Van Nierop et al. (2013) used a combination of static and time-varying MF exposure using an MRI to assess MF effects on postural control. Time-varying MFs were produced using standardized head movements while participants stood next to a 7 T MRI. Participants stood on a force plate to assess their postural control immediately after inducing the time-varying MF via head movements. Subjects were exposed to a sham, low (490 mT/s), and high (700 mT/s) time-varying MF for 16 seconds, during which they performed 10 vertical and 10 horizontal head movements on 3 separate occasions. The static MF was present the entire time during the high and low exposure conditions (low = 240 mT and high = 370 mT), but was not present during the sham condition. Results showed an increase in the size and the velocity of the sway pattern (as measured using sway path, area, and velocity characteristics) upon exposure to the induced time-varying MF compared to sham. Higher exposure levels had a greater effect. Since the time-varying MFs were induced with head movements within a static MF, participants were exposed to both types of MFs. Therefore, it is not possible to distinguish whether the observed effects were due to the time-varying MF or static MF component.

Additional work by van Nierop et al. (2015) assessed effects of time-varying MFs on vestibular related functions in two protocols. The first aimed to assess nystagmus and postural stability in a static MF compared to a static MF + time-varying MF (movement-induced) condition using a 7 T MRI (static MF: 1,000 mT, time-varying MF: 2,400 mT/s). They found a stabilization effect (decreased sway path) with exposure to static MF + time-varying MF compared to just the static MF condition and nystagmus was not induced in any of the conditions. This was concluded to be due to the static MF being too low to result in nystagmus. The second protocol explored whether the vestibular responsiveness to static MF (370 mT) and time-varying MF (700 mT/s) modifies test performance on a variety of cognitive function tasks, including recall of a short story, placing dots in a circle, and marking the middle of 20 horizontal lines as fast as possible. Vestibular responsiveness before testing was assessed using caloric reflex testing, rotary chair testing, and a subjective sensitivity to motion sickness questionnaire.

Results showed a significant interaction between static MF + time-varying MF exposure and unilateral weakness in all tasks. This included a stabilization effect (decreased sway path) in the static MF+time-varying MF condition compared to the sham condition for those with unilateral horizontal canal weakness. In terms of the cognitive function tasks, the static+time-varying MF condition showed significantly decreased verbal memory and visual acuity compared to sham.

Combining the results of the two previously mentioned studies, we can see a discrepancy. The first study (L. E. van Nierop et al., 2013) found a destabilization effect with exposure to static MF + time-varying MF compared to sham. Both protocols in the second study (L. van Nierop, 2015) found a stabilization effect with exposure to static MF + time-varying MF compared to sham. These different results cannot be explained by exposure levels, exposure duration or position of the participant on the force plate, as the two protocols were the same in this regard. However, the balance task in the first study was preceded by a 65-minute long MF exposure and cognitive task performance. The second study used only a 30-minute MF exposure prior to the postural control task. Therefore, it is possible that longer MF exposure is related to a destabilization effect whereas shorter MF exposure is related to a stabilization effect. Testing the effects in a single study protocol is important for establishing these results. Also, it is noteworthy that based on these results it is still not possible to distinguish the source of this effect as this experimental protocol does not allow for a time-varying MF only exposure.

Table 1: Summary of studies exploring the effects of MFs on human standing balance.

Study	Parameters		Field Type and Intensity			Findings		
	n-size	Exposure duration	Time-Varying	Static	Pulsed	COP	Reported Vertigo, Nausea, or Dizziness	Nystagmus
Theysohn et al., 2014	46	30 min		1.5 T 7 T		↑ sway path (mean and length – 2 minutes post-exposure)		
Glover et al., 2007	10	40 s		0.8 T		↑ mean forward displacement	Vertigo sensation	
Roberts et al., 2011	12	25 min		3 T 7 T				Robust nystagmus throughout exposure
Mian et al., 2013	25	135 s	690 mT/s	6 T			Vertigo onset at 5,140 mT	Nystagmus onset at 1,670 mT
Van Nierop et al., 2015	36	16 s (time-varying MF) 30 min (static MF)	700 mT/s	370 mT		↓ sway (path)		No nystagmus
Van Nierop et al., 2013	30	16 s (time-varying MF) 65 min (static MF)	490 mT/s 700 mT/s	240 mT 370 mT		↑ sway (path, area, and velocity)		
Glover et al., 2007	10	30 s	1.5-6 T/s	7 T			Vertigo sensation Nausea & dizziness	
Glover et al., 2007	12	5 s	2 T/s 127 mT (2.5 Hz)			No significant COP effects	No vertigo sensation	
Legros et al., 2012	73	60 min	*680 mT/s 1.8 mT (60 Hz)			↓ sway (amplitude and velocity)		
Glover et al., 2007	12	5 s			50 mT	No significant COP effects	No vertigo sensation	
Thomas et al., 2001a	24	2 min			0.2 mT	↓ sway (anterior-posterior path)		
Thomas et al., 2001b	45	2 min			0.2 mT	↓ sway (Romberg Quotient)		
Prato et al., 2001	35	2 min			0.2 mT	↑ sway (Romberg Quotient) in low light (0.12 W/m ²) No change in high light (0.51 W/m ²)		
*Estimated value calculated based on a uniform 1.8 mT, 60 Hz time-varying MF								

Glover et al. (2007) also studied the effects of time-varying MFs on the vestibular system by assessing postural control using force plate data. This study combined three protocols in which participants were exposed to different MF exposures: a static MF (static subject), a static MF (moving subject), and a time-varying MF (static subject). The first protocol was described in the previous section as significantly increasing mean forward displacement. The second protocol involved moving the participants slowly into the static MF of the 7 T MRI and then instructing them to make uniform head movements once positioned there. For this condition, participants were lying down in the MRI and they described their overall experiences. Results from this condition showed that 7 of 10 participants reported perceived movement inconsistent with their actual movement in the moving participant condition. MF-induced vertigo effects (9 of 10 participants) such as nausea (2 of 10 withdrew due to severe nausea) and dizziness (8 of 10) were also reported. The third protocol involved a time-varying MF with a static subject. Subjects were exposed to a MF at 5-second intervals during eight 1-minute trials while standing on a force plate for COP assessment. Four exposures used a sinusoidal stimulus (2.5 Hz, 2,000 mT/s, 127 mT peak) and four used a pulsed stimulus (0.5 s duration, 2,000 mT/s, 50 mT peak). Results showed that there was no detected effect of MFs on COP and there was no reported sensation of sway by the subjects. This study is significant in that it delivered a time-varying MF independent of a static MF through a solenoid coil exposure system. Unfortunately, the result of the static MF (moving subject) condition is not directly comparable to the other two protocols since COP could not be analyzed with the subjects lying down. However, it seems as though there is a destabilization effect in response to static MF exposure and no exposure effect for time-varying MF or pulsed MF exposures. This suggests that perhaps movement-induced time-varying MF exposures within an MRI are due to the constant presence of the static MF. It could also suggest that the time-varying MF produced with these head movements is significantly different from those produced by solenoid coils. The fact that different outcomes that may not result from the same neurophysiological pathways are reported makes interpretations difficult.

A study by Legros et al. (2012) was also able to directly test time-varying MFs and their effects on postural control without the presence of the static MF of an MRI. They studied the effects of time-varying MFs (60 Hz, 1.8 mT) in humans using an exposure system constructed of octagonal coils to produce a homogeneous time-varying MF at the level of the participant's head. Note that although the MF flux density is much lower than with MRI, the signal is given at a

higher frequency, which brings the dB/dt in the same order of magnitude (680 mT/s in the Legros' study). Participants were exposed for 1 hour after which they completed a series of tasks, including a postural oscillation recording. Force plate recordings showed a stabilization effect in terms of decreased velocity and amplitude of postural control oscillations for the MF condition compared to the sham condition. These effects were only observed during the eyes closed conditions. This suggests that the time-varying MF acts on proprioceptive or vestibular functions, a finding consistent with results from Glover et al. (2007). Comparing COP of Glover et al. (2007) and Legros et al. (2012), there appears to be some discrepancies in that no stabilization or destabilization effects were found for the former and a significant stabilization effect was found for the latter. This could be due to significant differences in the exposure apparatus between the two studies, thereby changing the MF distribution patterns. For example, Glover et al. (2007) used a 2.5 Hz stimulus, compared to a 60 Hz stimulus used by Legros et al. (2012). Therefore, it is possible that a frequency threshold somewhere between 2.5 and 60 Hz determines the observed stabilization response. A single study testing different frequency levels at a single MF value could provide more information on potential threshold effects. Indeed, considering the previous studies, there is likely a threshold effect to be determined in terms of exposure time, frequency, and intensity. The study we are conducting will address this possibility, as explained in the following chapters. Another consideration possibly accounting for observed differences in postural control results is the stance of each participant on the force plate. Van Nierop et al. (L. van Nierop, 2015; L. E. van Nierop et al., 2013) had participants stand with their feet together in a parallel position (0 cm apart) on a foam layer, whereas Legros et al. (2012) had participants stand with 1 cm between the feet in a parallel position with no foam layer. Glover et al. (2007) also used a foam layer, but provided no information on the spacing of participants' feet. It is therefore possible that the destabilization effects noted in the van Nierop et al. (2013) study was found due to the participants being in a less stable position than the positioning reported by Legros et al (2012).

Another category of time-varying MFs to be considered is pulsed MFs. A few studies have been conducted on the topic of postural control in response to pulsed MFs (Thomas, Drost, & Prato, 2001; Thomas, White, Drost, Cook, & Prato, 2001). The first of these studies (Thomas, Drost, et al., 2001) exposed 24 healthy participants to a pulsed (0.2 mT, 700 mT/s, 0-500 Hz) MF for 2 minutes at a time while standing on a force plate. Results showed significant

stabilization effect in terms of center of pressure. This was primarily observed through a decrease in distribution (range) of front-back motion. A second study (Thomas, White, et al., 2001) compared the effects of the same pulsed (0.2 mT, 700 mT/s, 0-500 Hz) MF between fibromyalgia, rheumatoid arthritis, and healthy individuals, using a similar experimental design as Thomas et al. (2001). Results again showed a significant stabilization effect in terms of an improved (decreased) Romberg Quotient (COP length in eyes closed measure divided by COP length in the eyes open measure (Nardone, Tarantola, Giordano, & Schieppati, 1997) upon exposure to the pulsed MF compared to sham. Levels of improvement differed between healthy patients and fibromyalgia or rheumatoid arthritis patients, suggesting an application in terms of diagnosis using pulsed MFs. Another experiment (Prato, Thomas, & Cook, 2001) studied the effects of a pulsed MF (0.2 mT, 700 mT/s, 0-500 Hz) on postural control in different low (0.12 W/m²) and high (0.51 W/m²) intensity light conditions. A force plate recorded COP patterns and the Romberg Quotient was used for analysis. The pulsed MF condition showed a significant destabilization effect (increased Romberg Quotient) compared to sham under the low light condition only. This suggests a light-dependent effect of pulsed MFs on human postural control with lower light levels having more of a destabilization effect compared to high light levels. Considering the previous three studies, it appears that this particular stimulus (0.2 mT, 700 mT/s, 0-500 Hz MF) can have a stabilizing effect except for in low light conditions where it has a destabilizing effect. This is coherent with the proposal that a destabilization of postural control leads to a greater effect of MFs on the vestibular system. This is achieved, for example by having participants close their eyes or reduce the lighting levels and having them stand with their feet directly together. No further studies have been found on the effects of pulsed MFs on human postural control.

Overall assessment of these studies shows inconsistent results. It is clear when considering only static MFs that a consistent destabilization effect is present. However, when considering movement-induced time-varying MFs within the static MF of an MRI, inconsistencies emerge with evidence supporting both destabilization and stabilization type effects. The fact that the movement itself might also interfere with the measured outcome has to be considered. Results of studies considering time-varying MF exposure are also varied with evidence of a stabilization effect and evidence supporting no exposure effect at all. When considering pulsed MFs, most studies consistently show a stabilization effect. However when

using low light conditions, there can be a destabilization effect as well. Since very few studies have been conducted in this research area, it is difficult to make direct comparisons. Further research is warranted to be able to better explain some of these discrepancies. Additionally, these studies do not inform us about potential mechanisms of action for vestibular responses to time-varying MF exposure. We will attempt to explore this in the next section.

1.9 Proposed mechanisms of action for MF exposure

There are a number of studies that explore the mechanism of action behind the observed effect of vestibular disruption due to MFs (see Table 2 for summary). In this section, we will explore the plausibility of the three main proposed mechanisms of action, as proposed by Glover et al. (2007): Magnetohydrodynamics, diamagnetic susceptibility, and induced electric fields and currents. It is noted that mechanisms of action proposed for direct current sources (GVS) were previously explored separately in section 1.6.1. This is because mechanisms of action proposed for a direct current source are not easily comparable to proposed mechanisms of action from an alternating current or time-varying MF source.

Table 2: Summary of proposed mechanisms of action for MF exposure.

Study	Proposed Mechanism			
	Stimulation	Force/Mechanism	Affected Area	Outcome
Fitzparick & Day, 2004	GVS	Direct current exposure	Vestibular afferent neurons (otoliths and semi-circular canals)	Postural instability Nystagmus Vertigo
Roberts et al., 2011	Static MF	Magnetohydrodynamics (Lorentz Force)	Cupula of the semicircular canal	Vertigo
Mian et al., 2013	Static MF	Magnetohydrodynamics (Lorentz Force)	Cupula of the semicircular canal	Vertigo Nystagmus
Theysohn et al., 2014	Static MF	Magnetohydrodynamics (Lorentz Force)	Vestibular organ	Vertigo
Van Nierop et al., 2015	Static MF	Magnetohydrodynamics (Lorentz Force)	Cupula of the semicircular canal	Oculomotor and postural stability outcomes
Glover et al., 2007	Static MF	Diamagnetic susceptibility	Otolithic membrane	Vertigo
	Time-varying MF (movement-induced)	Induced electric field	Vestibular hair cells Vestibular afferent neurons	Vertigo
Van Nierop et al., 2015	Time-varying MF (movement-induced)	Induced current	Cerebral neurons	Altered neurocognitive performance

1.9.1 Magnetohydrodynamics

The first proposed mechanism, magnetohydrodynamics, describes the flow of conducting fluids (such as blood or endolymph fluid) in electromagnetic fields and how these fields allow for forces to arise in the fluid due to induced currents. These forces act on the cupula and thereby cause a perceived accelerated movement. This is the widely accepted mechanism of action described for the observed effects of static MF exposure on vestibular functioning. We will present studies that explain this effect in terms of static MFs followed by the potential for magnetohydrodynamics to be applied to time-varying MFs.

A study by Roberts et al. (2011) proposed the Lorentz force (one of the forces described by magnetohydrodynamics) as the cause of vertigo sensation for participants in the static field of an MRI. This force was described as a resulting interaction between ionic currents in the endolymph fluid (within the labyrinth of the vestibular system) and the MF. Specifically, forces due to the interaction of the MF with the induced ionic current become noticeable when they have a similar magnitude to the inertial force of the fluid, potentially causing perceived movements. These forces act directly on the semicircular canal cupula (see section 1.4.2), which upon bending, leads to stimulation of the adjoining hair cells and therefore the hair cells themselves are not directly affected. The calculated pressure exerted by the Lorentz force on the cupula (0.002-0.02 Pa) by a 7 T MRI exceeds the nystagmus threshold (0.0001 Pa), thus being a sound proposal for the mechanism of action behind the observed nystagmus. Further modeling work by Antunes et al. (Antunes, Glover, Li, Mian, & Day, 2012) supported the hypothesis of a Lorentz force being a significant contributor to static MF-induced nystagmus as reported by Roberts et al. (2011) and Mian et al. (2013).

Work by Mian et al. (2013) sought to further explore whether static MF-induced vertigo can be explained by a similar mechanism of action as static MF-induced nystagmus (via the Lorentz force). Participants' eye movements and perceived vertigo were noted while being pushed into a 7 T MRI. Results suggested that the perception of vertigo and observed nystagmus share similar mechanisms of action (that is a Lorentz force acting on the semicircular canal cupula). This is due to the participants describing a rotational perception of vertigo (consistent with semi-circular canal involvement), a dependence on MF direction (through reversal of perceived rotation when the participant enters the MRI feet-first vs. head-first), and the perception of vertigo still being present while the participant is stationary. According to this

proposed mechanism, MF induced nystagmus and vertigo is therefore not dependent on movement inside MFs, MF gradients, or time-varying MFs. Rather, it is dependent on naturally occurring ionic currents in the endolymph fluid, which can be modulated by MF magnitude and direction.

Theysohn et al. (2014) used previous literature combined with their test results to determine the mechanisms of action for induced vertigo within the static MF of MRIs. They surmised that vertigo generation was not caused by the gradient system or the radiofrequency excitation, since turning off each of these components in turn did not diminish the observed postural instability effect. Overall, they proposed that a compensatory response in the vestibular organ, similar to the mechanism of action proposed by Roberts et al. (2011), explains the observed vertigo effects as they were only detected after a prolonged exposure in a static MF with no participant movement.

Glover et al. (2007) looked into the applicability of magnetohydrodynamics to time-varying MF effects on the vestibular system. They concluded that these magnetohydrodynamic forces are unlikely to be of relevance in the vestibular system due to the small size of the vestibular structure and the fluid conductivities being too low to induce such a force. However, they suggested it is possible to see these effects in larger arteries or at MFs greater than 7 T (Kangarlou & Robitaille, 2000). Van Nierop et al. (2015) support this in concluding that a 1,000 mT static MF induced Lorentz force would be too weak to produce a detectable horizontal nystagmus. Considering this, it seems that magnetohydrodynamics serve as an excellent basis for explaining the effects of static MFs on the vestibular system in MRIs, which have the ability to produce large MF values above 7 T. Alternatively, they cannot be applied to the studies conducted so far on time-varying MFs which use much lower magnetic flux densities. This difference in proposed mechanisms of action for static compared to time-varying MFs could also explain some of the discrepancies found in standing balance studies as discussed in the previous section (section 1.8).

1.9.2 Diamagnetic susceptibility

The second mechanism described is diamagnetic susceptibility, which describes a net force that arises due to an interaction between the induced magnetic dipoles of a material and the MF itself. Such a force can affect the otoliths when exposed to an inhomogeneous MF due to the difference

in density and therefore magnetic susceptibility between the otoliths and their surrounding fluid. Glover et al. (2007) support this mechanism of action to describe the observed sway modifications for subjects standing near the MRI as it is the only mechanism described that is not dependent on movement within the field. It is noteworthy to include that it is highly difficult to assess the effects of this mechanism on other structures of the vestibular system. Indeed, structures such as the semicircular canals have different fluid dynamics and densities to consider. No other studies have directly reported on this mechanism of action in terms of MF exposure in human.

Diamagnetic susceptibility has also been studied in the context of animal orientation and homing abilities. A homing ability is an animal's ability to return to a given location after traveling a significant distance from it. It was found that in the presence of man-made electromagnetic noise, the homing mechanism of migrating birds was disrupted (Engels et al., 2014). A study by Wu and Dickman (2012) further explored the homing mechanism in pigeons in which they described special cells that code for MF intensity, direction, and polarity of earth's geomagnetic field. These characteristics are all a necessary and integral part for animal homing abilities. With respect to humans, this mechanism may not be relevant in the vestibular system since humans do not possess the sensitivity in their vestibular cells to detect earth's geomagnetic field of only 35-70 μT (Wu & Dickman, 2012).

1.9.3 Induced current and electric fields

Induced currents and electric fields are the basis of the mechanism of action used to explain magnetophosphenes perception (Laakso & Hirata, 2012) and therefore serves as an important mechanism of action to consider. Van Nierop et al. (2015) explored the working dynamics of MF induced nystagmus proposing a mechanism for time-varying MF exposure involving electromagnetic induction. This is described using Faraday's Law, which states that changing the MF flux density, for example by moving through a static MF, induces a current in the human body. They proposed that these induced currents are above the neuron membrane depolarization threshold, thus affecting the generation of an action potential in any given neuron in the exposed area. They suggested that this is the most plausible mechanism describing cognitive changes, including visual perception and visuomotor function. This is consistent with previous work by Fitzpatrick & Day (2004), who proposed that GVS (a direct current) affects the afferent neuron

in the vestibular system, causing a perceived motion. It is therefore possible that time-varying MFs of sufficient strength, which also have the capability of inducing a current, will have a similar effect at the level of the vestibular system.

Glover et al. (2007) proposed a similar mechanism of action, which they termed induced galvanic vestibular stimulation. This is described as changes in the electric field across the vestibular hair cells of the semicircular canal cupulae and otolithic membrane thus modulating their afferent neuron's firing rate and giving an artificial perception of movement. They concluded that movements or rotations in gradients or homogeneous MFs could cause perceived movements via induced galvanic vestibular stimulation and that this is a polarity-sensitive effect. A polarity-sensitive effect is an effect dependent on a difference in charge for the anode compared to the cathode in terms of GVS. When considering the vestibular system this is seen as a difference in charge on one side of the head compared to the other. Versluis et al. (2013) also support induced current acting directly on hair cells as a viable mechanism of action.

In conclusion, this section had outlined general background information on MFs and their potential interactions with the human vestibular system. We discovered that time-varying MFs have the potential to affect normal human postural control. This previous research however shows inconsistencies in the results found, which warrants the need for further investigation. For example, some studies are showing a stabilization effect with respect to time-varying MF exposure (Legros et al., 2012; Thomas, Drost, et al., 2001; Thomas, White, et al., 2001; L. van Nierop, 2015), some are showing a destabilization effect (Prato et al., 2001; L. E. van Nierop et al., 2013), and some are showing no effect at all (Glover et al., 2007). These studies all differ in duration of exposure, type of exposure used, and experimental design, making them difficult to compare and draw conclusions from. In the following section, we will explore the best means by which to further test the potential effects of time-varying MFs and electrical current stimulation on the human vestibular system through analysis of postural control.

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Chapter 2

2 Research Article

2.1 Introduction

Magnetic fields (MFs) are a part of our everyday lives with humans being exposed to both natural and manmade MF sources. These time-varying MFs, such as those produced by power-lines in the extremely low frequency range (< 300 Hz), have the property to induce electric fields (E-fields) and currents in conductors. As a conductor, the human body is susceptible to these E-fields and induced currents, which have the potential to modulate biological processes. Average levels of public exposure to these ELF MFs are on the order of $0.1 \mu\text{T}$, including residential and rural areas (ICNIRP, 2010). They can reach higher levels of up to 2 mT when using certain electrical household appliances, such as hair dryers (Gauger, 1985), electric hair clippers (Gandhi, Kang, Wu, & Lazzi, 2001), electric shavers and electric drills (Lambrozo, 2013). For live power-line workers, exposure levels reach over 2 mT (Gandhi et al., 2001) and for those working closely with high current conductors, such as live-line electric utility workers, exposure levels reach up to 10 mT (WHO, 2007). Therefore, it is important to consider potential interactions MFs could have on our biology and behavior. This helps to further establish exposure guideline recommendations for workers and the general public.

A well-established biological effect of ELF MF exposure, known as magnetophosphenes (Attwell, 2003; d'Arsonval, 1896; Lovsund, Oberg, Nilsson, & Reuter, 1980; Souques et al., 2014), is an instantaneously occurring flickering visual perception. These flickering perceptions were first reported in 1896 (d'Arsonval, 1896) and have been investigated since then in terms of determining a threshold for observed effects. However, uncertainty on this threshold for an acute response remains. The reference study reports a lowest threshold for magnetophosphene perception at 8.1 mT in the dark for a MF stimulus delivered at 20 Hz (Lovsund et al., 1980). This well documented biological effect calls into question whether other acute biological effects can be observed upon exposure to ELF MFs. Interestingly, previous research has shown modulations of postural control in the presence of ELF MFs in humans (Legros et al., 2012; Prato, Thomas, & Cook, 2001; Thomas, Drost, & Prato, 2001; Thomas, White, Drost, Cook, & Prato, 2001; L. van Nierop, 2015; L. E. van Nierop, Slottje, Kingma, & Kromhout, 2013). The

control of posture is enabled by the integration of information gathered by the visual, auditory, sensory-motor, and vestibular systems (Karlberg, 1995; Magnusson, Enbom, Johansson, & Wiklund, 1990; Stal, Fransson, Magnusson, & Karlberg, 2003). The vestibular system is of particular interest for it is responsible for controlling gaze stabilization and maintaining the position the head with respect to the rest of the body. It therefore controls the overall balance in humans. However, the literature results regarding the possible impact of ELF MFs on postural control and on the vestibular system remain inconsistent. For example, some studies are showing a stabilization effect with respect to time-varying MF exposure (Legros et al., 2012; Thomas, Drost, et al., 2001; Thomas, White, et al., 2001; L. van Nierop, 2015), some are showing a destabilization effect (Prato et al., 2001; L. E. van Nierop et al., 2013), and some are showing no effect (Glover, Cavin, Qian, Bowtell, & Gowland, 2007). These studies all differ in duration of exposure, type of exposure used, and experimental design, making them difficult to compare and draw conclusions from.

Several mechanisms of action have been presented for interactions between MFs and tissues. First, the magnetohydrodynamic forces, such as Lorentz forces, are the possible consequences of MF on moving conductive fluids (such as blood or cerebrospinal fluid). Second, the diamagnetic susceptibility describes the effect of MFs on any structure (such as the vestibular system) depending on their density. Finally, a commonly agreed upon mechanism of action for the aforementioned observed effects is that time-varying MFs have the ability to change the E-field and induce current across the vestibular system. Specifically, these induced fields are proposed to affect the vestibular hair cells, which are the vestibular sensors responsible for detecting head accelerations. The information received from the hair cells give rise to the perception of motion, which is then corrected for to maintain overall postural stability (Glover et al., 2007; L. van Nierop, 2015). Magnetohydrodynamics and diamagnetic susceptibility have been presented as unlikely to cause the observed time-varying MF effects (Glover et al., 2007). This emphasizes the importance of studying the effects of induced currents on human vestibular functioning.

As previously introduced, a well-known methodology to stimulate the vestibular system with current, called Galvanic Vestibular Stimulation (GVS), has been used to induce changes in postural control (Fitzpatrick & Day, 2004). This method consists of applying a transcranial Direct Current Stimulation (tDCS) at the level of the mastoid process, which modulates the firing

rate of the vestibular afferents. This leads to a perceived head acceleration, which results in a compensatory tilt towards the exposure side (Fitzpatrick & Day, 2004). For clarification purposes, the term GVS will be used from this point forward to describe a DC current targeting the vestibular system. With transcranial Alternating Current Stimulation (tACS), which is developed to apply AC currents to human brain, it becomes possible to investigate the potential impact of AC currents applied directly to the vestibular system. This is of fundamental interest when one hypothesizes that the vestibular effects of time-varying MF reported in the literature might result from an induced-current mechanism. Interestingly, the potential effects of tACS on human postural control have not yet been explored even though it is capable of delivering currents at the level of the human vestibular system comparable to those produced by GVS (Ferdjallah, Bostick, & Barr, 1996; Merlet et al., 2013).

The main objective of this study was to determine if a MF at flux densities inducing E-field and currents comparable to GVS (already known to produce an acute postural control effect) is capable of triggering an acute postural response in humans. In order to confirm that the effect, if observed, is related to induced current mechanisms, the same protocol is delivered using tACS. Exposing healthy participants at high flux density levels (up to 100 mT), and different selected frequencies in the ELF range enables us to explore potential acute vestibular responses and frequency effects of ELF MFs on human postural control.

In this work, we first tested whether time-varying stimulations (tACS and MFs) produce different postural outcomes depending on the frequency of the stimulation. Second of all, we tested whether GVS produces adjustments in postural control that depend on the side of exposure as a positive control condition, and we verified whether such effects can be observed with tACS and time-varying MFs. Finally, we tested whether the different exposure techniques (GVS, tACS, and time-varying MFs) were producing postural adaptations different than those observed when no stimulation is applied. We hypothesize that GVS, tACS, and time-varying MFs will produce postural adaptations different than those produced during a sham condition, and that postural outcomes (if present) will be frequency dependent.

2.2 Materials and Methods

2.2.1 Participants

Twenty two healthy participants (12 males, 10 females, mean age: 23 ± 4.85) were tested in the

Human Threshold Research Facility at St. Joseph's Hospital in London, Ontario, Canada. Inclusion criteria included healthy participants (males and females) between the ages of 18 and 55. Exclusion criteria for the study included history of vestibular-related pathology (such as benign paroxysmal positional vertigo (BPPV), labyrinthitis or vestibular neuritis, Ménière's disease, secondary endolymphatic hydrops and perilymph fistula), chronic illnesses (including cardiovascular diseases, such as hypertension, ischemia, and cerebrovascular disease) and neurological diseases that affect normal body movement (such as Parkinson's disease or Multiple Sclerosis). Additional exclusion criteria include people being treated for hypertension and people who are prone to seizures, self-reported permanent metal devices or piercings above the neck region, use of soft or hard drugs, and excessive alcohol or caffeine intake. This protocol was approved by Western University's Ethics Board for Health Science Research Involving Human Subjects (protocol #106122).

2.2.2 Materials

We used a force plate (OR6-7-1000, AMTI, USA) to record the force and moment applied by each participant on the surface of the platform. Data were recorded at 10 kHz, using an A/D National Instrument card (NI SCB-68A, National Instruments, USA), driven by LabVIEW 14.0.1 (National Instruments, USA). The LabVIEW program was used to acquire force (F) and moment (M) data in 3 dimensions from the force plate and write them to a single measurement file, along with MF data and time stamps for synchronization purposes with the electrical stimulation conditions. The trajectory of Center Of Pressure (COP) was calculated from these force and moment data using a calibration matrix provided by the manufacturer. No hardware filtering was applied to these data.

The GVS and tACS were delivered using the StarStim system (StarStim, Neuroelectronics, Spain – see Figure 5 for StarStim stimulation device). Two Sponstim sponge electrodes were placed at F3 and F4 and 2 Pistim gel electrodes were placed at M1 and M2, using the International 10-20 system. The tACS exposure follows the distribution pattern from M1 to F4 (stimulation anode on the left) and M2 to F3 (stimulation anode on the right) in order to provide maximal vestibular system stimulation (Merlet et al., 2013). The GVS exposure follows the distribution pattern from M1 to M2 (stimulation anode on the left) and from M2 to M1 (stimulation anode on the right) to allow for maximal vestibular stimulation (Miranda et al.,

2006). NIC software (StarStim, Neuroelectronics, Spain) was used to drive the StarStim device via Bluetooth and force plate recordings were synchronized via timestamp. The MF exposure was delivered via a customized head set coil exposure system, consisting of two 570 turn-coils of 5.9 cm of mean diameter, with a 2 cm diameter core of Permendur-49 (The Goodfellow Group, Coraopolis, PA, USA). The coils were attached to an adjustable helmet-like device, suspended on a pulley system to allow for free movement of the participant's head and body (see Figure 5 for the helmet exposure device). The pulley system, not shown in the images, consisted of a single pulley fixed directly above the participant's head, oriented in the direction of the coronal plane to allow for bilateral body movements. One end of the string passing through the pulley system was attached to the helmet device and the other end to a counterbalanced weight. Without the pulley system, the exposure apparatus weighs 14.75 pounds (or 6.69 kg). With this system, the net weight supported by the head of the subject is null. The coil system was driven by the same A/D National Instrument module (NI SCB-68A, National Instruments, USA) as used to acquire force plate data, driven by the same LabVIEW 14.0.1 (National Instruments, USA) program. The helmet exposure device was adjusted to fit directly beside each mastoid for maximal vestibular MF exposure. An alternating current was run through MRI gradient amplifiers (MTS AUTOMATION, Model 0106475, USA) to produce a 50 and 100 mT MF flux densities respectively, at 3 cm from the coil surface (see Figure 6). A MF probe was placed directly on the back of the helmet and was always monitoring the MF values the participant was exposed to (a calibration process allowed to estimate the MF flux density at 3 cm inside the mastoid exposure).



Figure 5: Starstim system used for the tACS and GVS stimulation conditions (left panel) and the MF exposure coils (one on each side of the head) attached to a helmet and also attached above to a working pulley system to balance weight of the coils (right panel).

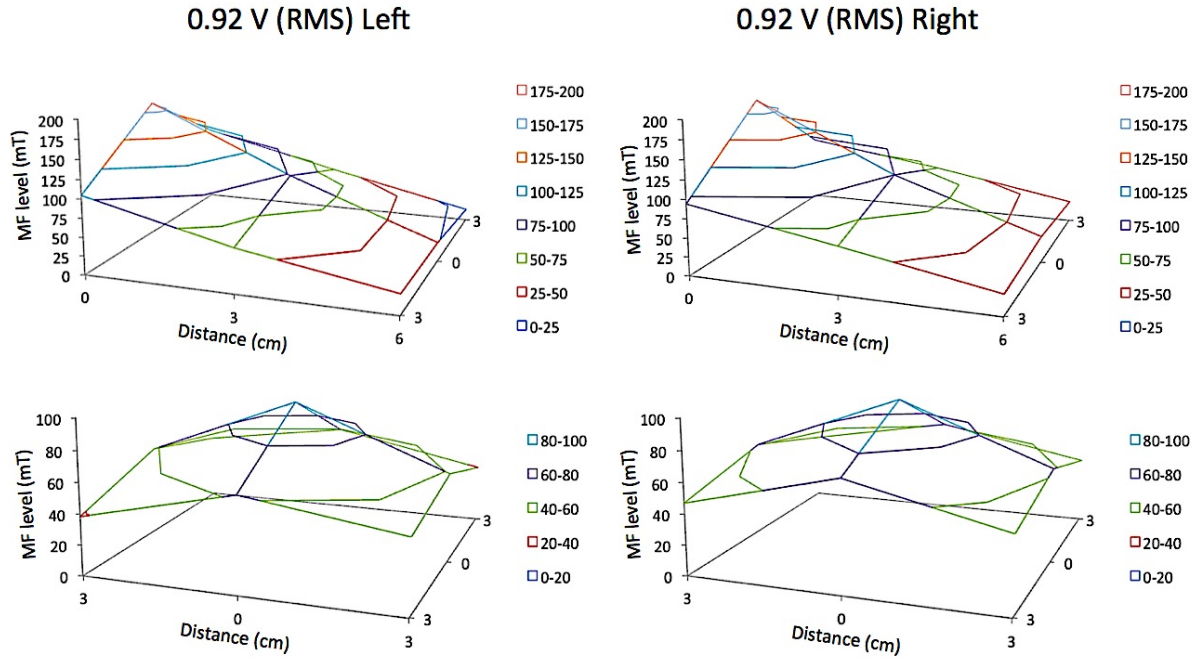


Figure 6: Distribution of MF flux density (in mT) produced by a 3.9 A_{rms} in the coil. The top two images represent a transversal plane and the bottom two represent a coronal plane at the target level of 3 cm from the surface of the coil. Data was collected using a MF probe.

2.2.3 Experimental Procedure

The experimental design consisted of a single study session lasting 2 hours and 15 minutes (Figure 7). The initial 20 minutes was devoted to the explanation of the study and obtaining written consent from the participant for study participation. The following 20 minutes was devoted to setting up the participant with the StarStim exposure device (cap and electrode placement on the head). Next, an impedance check was performed. Then the participant was exposed to a short GVS (1.5 mA, DC) and tACS (1.5 mA, 20 Hz) exposure as a familiarization sample before the actual testing took place. The actual testing sessions consisted of 33 randomized conditions, split up into 3 sessions of 11 conditions. Each session lasted approximately 25 minutes, with a 5-minute break between sessions.

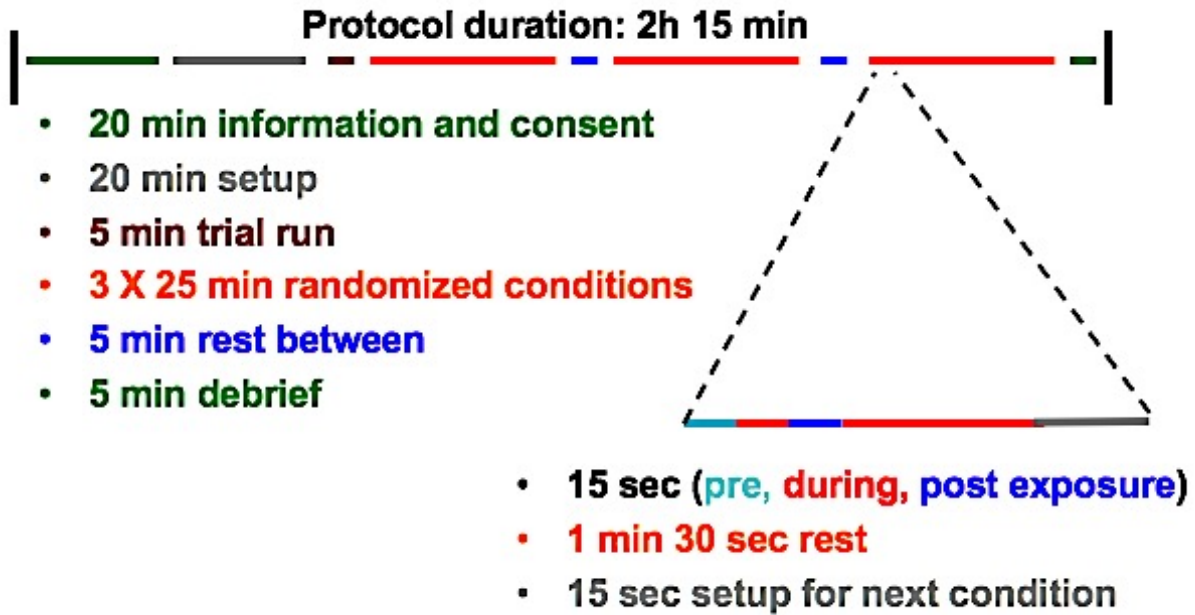


Figure 7: Breakdown of the study protocol in terms of timing. The overall protocol was 2 hours and 15 minutes in length, with the exposure sessions divided into 3 sets of 11 exposures.

Each condition consisted of two steps. First was a 30-second period of standing on the force plate, during which the participant was exposed to one of the stimulations for 5 seconds. Second was a 1.5-minute rest period where the participant stepped off the force plate and sat in a chair while a second experimenter set up for the next condition. While standing on the force plate, the participant stood with their feet together, arms resting at their sides, and eyes closed to minimize visual cues. The force plate itself was covered with a foam layer (1.5 cm thickness) to minimize proprioceptive cues about body positioning and the participant was given earplugs to minimize any audio cues. Both the StarStim exposure cap and the MF exposure device were on the head during all conditions for consistency. The participant was asked to stand 10 seconds before the end of the rest period, allowing for properly aligning the MF exposure device on the participant's head. The experimenter then instructed the participant to close their eyes, which is when the next 30-second postural control recording began.

The 33 randomized exposures consisted of: 1 Sham exposure where no stimulation was applied, 2 GVS 1.5 mA exposures (one on each side of the head), 10 tACS 1.5 mA exposures (5 on each side of the head, each at a different frequency of either 20, 60, 90, 120, or 160 Hz), and

20 MF exposures (10 on each side of the head with one of each of the 5 previously listed frequencies delivered at 50 mT and one of each of the 5 frequencies at 100 mT). These specific frequencies were selected for testing on the following basis: 20 Hz was selected because this is the optimal frequency of magnetophosphene perception (Lovsund et al., 1980), 60 Hz is the power line MF frequency in North America, 90 Hz is thought to be the resting hair cell firing rate (Fernandez & Goldberg, 1971; Goldberg & Fernandez, 1971), and 120 and 160 Hz were selected as frequencies above 90 Hz symmetrically from 20 and 60 Hz.

2.2.4 Variables and Statistical Analysis

Data analysis was conducted using a MatLab (MatLab version 9.0 – The MathWorks Inc., USA). First, the 3 forces and momentum time series were filtered using a low-pass filter at 10 Hz, which allowed to exclude MF frequencies used in the protocol. The trajectory of the COP was calculated from these filtered time series, and served as a basis to the calculation of sway characteristics. The variables analyzed from the COP data were the Path Length (cm), Area (cm^2), mean Coronal Velocity (cm/s), the Lateral Coronal Displacement (cm), and frequency domain analysis conducted on the Coronal Velocity (See Figures 8 and 9). Path Length was calculated as the sum of the distance between each sequential point of measurement. Area was calculated as the total enclosed area of the participant's movement using the minimum enclosed polygonal area of the plotted outer vertices using Matlab's convex hull function. The Coronal Velocity was calculated as the mean of the absolute Coronal displacement per sampling period. Lateral Coronal Displacement was calculated as a difference between the average centre of pressure position of a 5-second time period before exposure and the average centre of pressure position of the 5-second time period of exposure. A positive difference signifies a displacement to the right and a negative difference signifies a displacement to the left (Figure 8). A frequency domain analysis was conducted on the Coronal Velocity using a Fast Fourier Transform with Matlab's pwelch function using a 5-second time window and no overlap. In order to compare participants, we computed the normalized spectrum density and distinguished 3 different bands as described by Paillard and Noe (2015). A Low Frequency Band (LFB, 0-0.5 Hz), a Medium Frequency Band (MFB, 0.5-2 Hz), and a High Frequency Band (HFB, 2-10 Hz). Note that in the LFB, the first frequency is calculated based on the first point in the power band, which would have a value slightly higher than 0 Hz. The statistical analysis of the frequency bands was

performed using log-transformation of the normalized power density. A back-transformation was performed for representation of the results in tables and charts (McDonald, 2014).

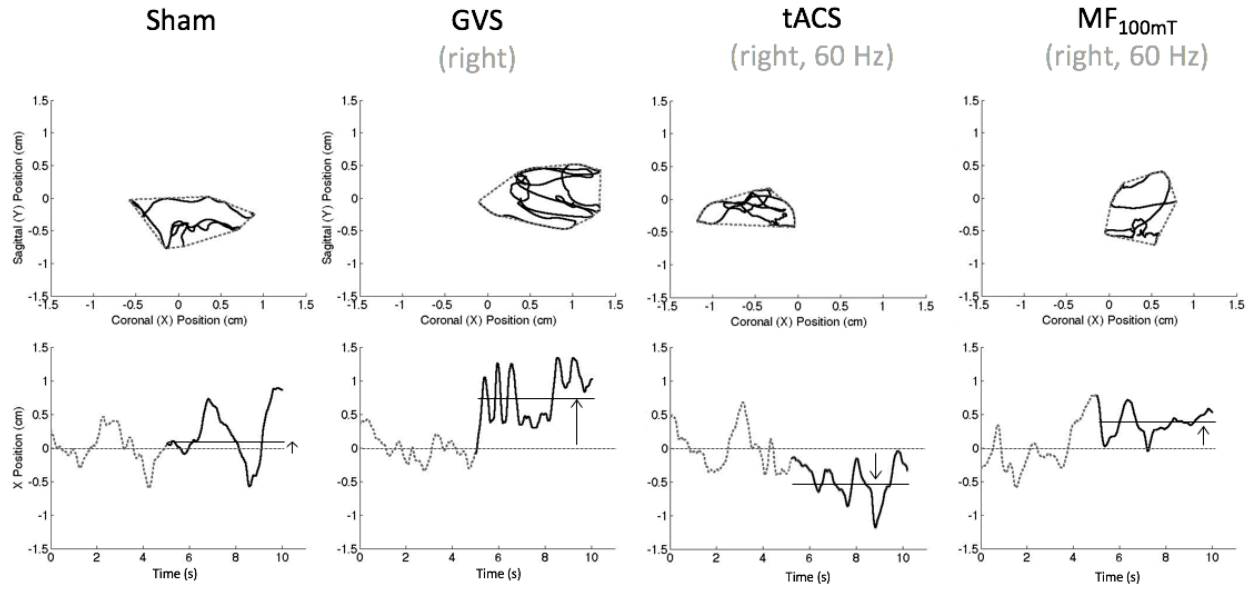


Figure 8: A representation of sway path (top panels dotted line), area (top panels solid line), and displacement along the coronal axis (bottom panels) for a single participant in the sham (first left panels), GVS (second to the left panels), tACS (second to the right panels), and MF_{100mT} (right panels) exposure conditions in the case of right side exposure conditions. In the bottom panels, the average coronal displacement is shown with a solid line and the arrow signifies the direction of average displacement to the right (up) or left (down) as a difference from the 5-second pre-exposure period (dotted line). The graphs shown are based on a single participant for visualization purposes of the selected sway characteristics. The visual inspection of these graphs show a clear displacement of the COP on the right during the GVS stimulation and a tendency to move on the left during the tACS stimulation. The MF_{100mT} exposure seem to be associated with a small displacement of the COP on the right (although not confirmed by statistical tests), and the sway stays unchanged during the sham condition as expected.

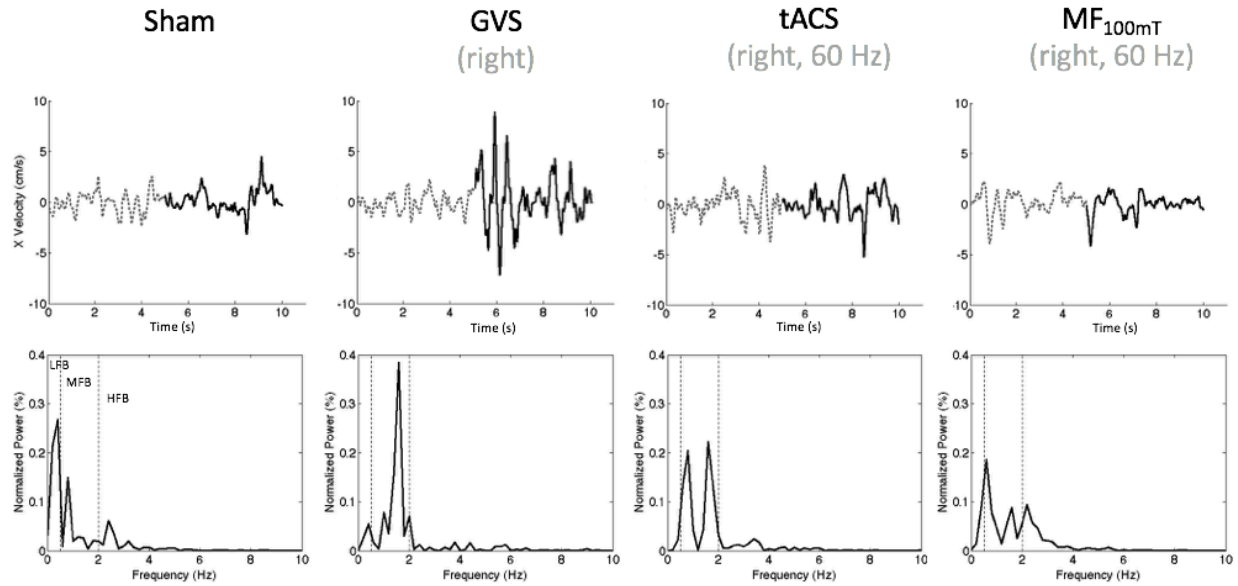


Figure 9: A representation of Coronal Velocity (top panels) showing the 5 second pre-exposure period (dotted line) and 5-second exposure period (solid line). The Frequency Domain analysis on Coronal Velocity (bottom panels) is shown for a single participant with the dotted line separating the different bands. Both characteristics are shown for the sham (left panels), GVS (second from the left panels), tACS (second from the right panels), and MF_{100mT} (right panels) conditions in the case of right side exposure. The graphs shown are based on a single participant for visualization purposes of the selected sway characteristics.

The visual inspection of these graphs show a clear increased Coronal Velocity during the GVS stimulation, and a high Power associated with the medium frequency band. There is a less clear velocity increase during the tACS stimulation, and a high power associated with the medium frequency band. The MF_{100mT} exposure seem to be associated with no change in Coronal Velocity, with a high power associated with the low and medium frequency bands.

The sway stays unchanged during the sham condition as expected, with a high power associated with the low frequency band.

The statistical analysis consisted of three separate ANOVAs for each parameter measured. The first ANOVA tested the Frequency effect for the different time-varying exposure types using a 3x2x5 ANOVA: The first factor was Exposure (3 levels: tACS, MF_{50mT} and MF_{100mT}), the second factor was Side of exposure (2 levels: left and right), and the third factor

was Frequency (5 levels: 20 Hz, 60 Hz, 90 Hz, 120 Hz and 160 Hz). For this test, the Sham and GVS conditions were excluded for the lack of Frequency conditions in these stimulations. The absence of a main frequency effect found in the first ANOVA allowed us to pool the frequencies for a second ANOVA. This second test explored the effect of side of exposure using a 2 by 4 ANOVA with the first factor being Side of exposure (2 levels: left and right), and the second factor being Exposure (4 levels: GVS, tACS, MF_{50mT}, and MF_{100mT}). For this second test, the Sham condition was excluded from the analysis since we could not compare Left and Right stimulation for the Sham exposure. Finally, we were able to pool the Side in a third ANOVA, since no major effects of exposure Side were found. This third test was a one-way ANOVA comparing the effect of the experimental exposures to the Sham (5 levels: Sham, GVS, tACS, MF_{50mT}, and MF_{100mT}). Post-hoc analyses were performed using a Bonferonni correction on all ANOVAs. SPSS Statistics software was used for all statistical analyses (SPSS version 24.0 – IBM, USA).

2.3 Results

2.3.1 First test: Effect of frequency for time-varying stimulations

In this first analysis, we excluded both Sham and GVS conditions in order to test any possible effect of the different frequencies of stimulations. A main effect of Exposure (also found in tests 2 and 3) was significant showing that tACS was significantly different than MF stimulations in terms of Path Length ($F(2, 42) = 11.57, p < .01$), Area ($F(2, 42) = 4.07, p < .05$), and Coronal Velocity ($F(2, 42) = 8.90, p < .01$), as seen in figure 10 for Path Length.

The Coronal Velocity HFB also showed a significant Exposure effect ($F(2, 42) = 5.20, p < .01$), which demonstrated a lower percentage attributed to the HFB for tACS ($0.16\% \pm 0.01$) compared to MF_{50mT} ($0.18\% \pm 0.01$) and MF_{100mT} ($0.19\% \pm 0.01$), as seen in Figure 11.

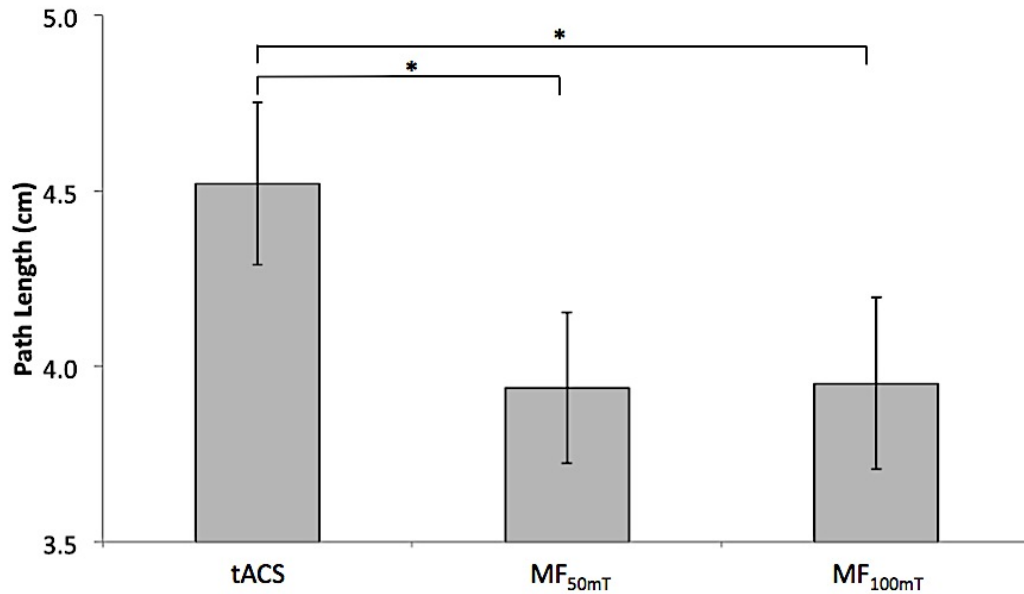


Figure 10: Effect of Exposure for the Path Length of (y-axis) variable representing all participants in the tACS, MF_{50mT}, and MF_{100mT} conditions (x-axis). As shown, the tACS condition had a higher path length (4.52 ± 0.23) than the MF conditions (3.94 ± 0.22 for MF_{50mT} and 3.95 ± 0.25 for MF_{100mT}), signifying a destabilization for tACS exposure compared to MF exposure.

The Coronal Velocity HFB showed a significant Side effect ($F(1, 21) = 6.30, p < .05$). This was seen in terms of a higher percentage attributed to the HFB for the left ($0.18\% \pm 0.01$) compared to the right ($0.17\% \pm 0.01$). However, it should be noted that this effect is contributing to less than 1% of the normalized power spectrum. No Side effects were found for any of the other measured sway characteristics, apart from Lateral Coronal Displacement in the second analysis.

No significant Frequency effects were found for any of the measured sway characteristics. However, a significant interaction between Exposure and Frequency was found in the Coronal Velocity HFB ($F(8, 168) = 3.14, p < .01$). This was seen in the post-hoc analysis in terms of a lower percentage attributed to the HFB for tACS exposures below 90 Hz compared to other frequencies and exposures (See Figure 11).

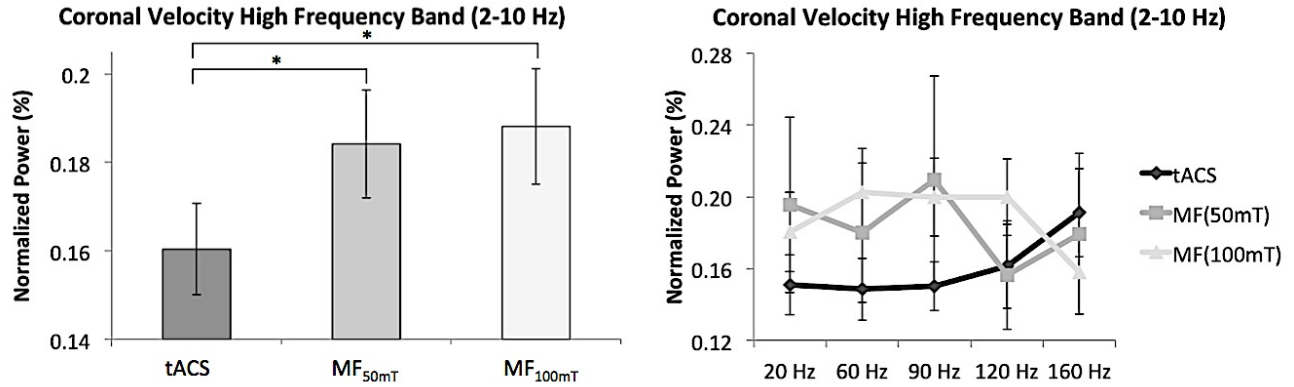


Figure 11: The frequency domain analysis exploring the Frequency effect for Coronal Velocity (High Frequency Band), comparing tACS, MF_{50mT}, and MF_{100mT} conditions. The exposure effect is shown in the left panel and the Exposure-Frequency interaction in the right panel. The left panel shows a lower percentage of the normalized power spectrum associated with tACS (0.16 ± 0.01) compared to the MF conditions (0.18 ± 0.01 MF_{50mT}, 0.19 ± 0.01 MF_{100mT}) in the HFB. The right panel shows a lower percentage of the normalized power spectrum attributed to the HFB for tACS below 90 Hz compared to other frequencies and exposures, although significance was not reached in post-hoc comparisons.

The Coronal Velocity HFB showed a significant Exposure*Side*Frequency interaction effect ($F(8, 168) = 2.37, p < .05$). Lateral Coronal Displacement also showed a significant Exposure*Side*Frequency interaction effect ($F(8, 168) = 2.36, p < .05$). Pairwise comparisons with Bonferroni corrections on all aforementioned interaction effects revealed no significant effects.

2.3.2 Second test: Effect of side of exposure for GVS as a positive control

In the second part of the analysis we tested the GVS as a positive control. In order to do so, we excluded the Sham condition for each subject and test the effect of the Side of exposure. First of all, a main effect of exposure was found, revealing an effect of Exposure on the Path Length ($F(3, 63) = 11.00, p < .01$), Area ($F(3, 63) = 7.86, p < .05$), and Coronal Velocity ($F(3, 63) = 10.25, p < .01$) attributed to GVS, as presented in Table 3. No significant effects were found for

the LFB, MFB and HFB of the Coronal Velocity.

The Lateral Coronal Displacement is of particular interest here since this variable elicits displacement towards one side of the body or the other. The Lateral Coronal Displacement was significantly different when exposed to stimulation on the right side of the head compared to the stimulation on the left ($F(1, 21) = 26.28, p < .001$). A left side exposure revealed a higher average displacement on the left ($-0.14 \text{ cm} \pm 0.04$) and a right side exposure showed a higher average displacement on the right ($0.17 \text{ cm} \pm 0.04$). Note that this main effect of side of exposure is considering the average of all conditions. This main effect of side of exposure is mainly due to the strong interaction between Side and Exposure that also revealed significant differences for Lateral Coronal Displacement ($F(3, 63) = 21.82, p < 0.001$). Figure 12 shows that the GVS exposure lead to average displacement to the left for a left side exposure ($-0.57 \text{ cm} \pm 0.14$) and average displacement to the right for a right side exposure ($0.70 \text{ cm} \pm 0.16$).

No significant effects of side or side-exposure interactions were found for the other variables.

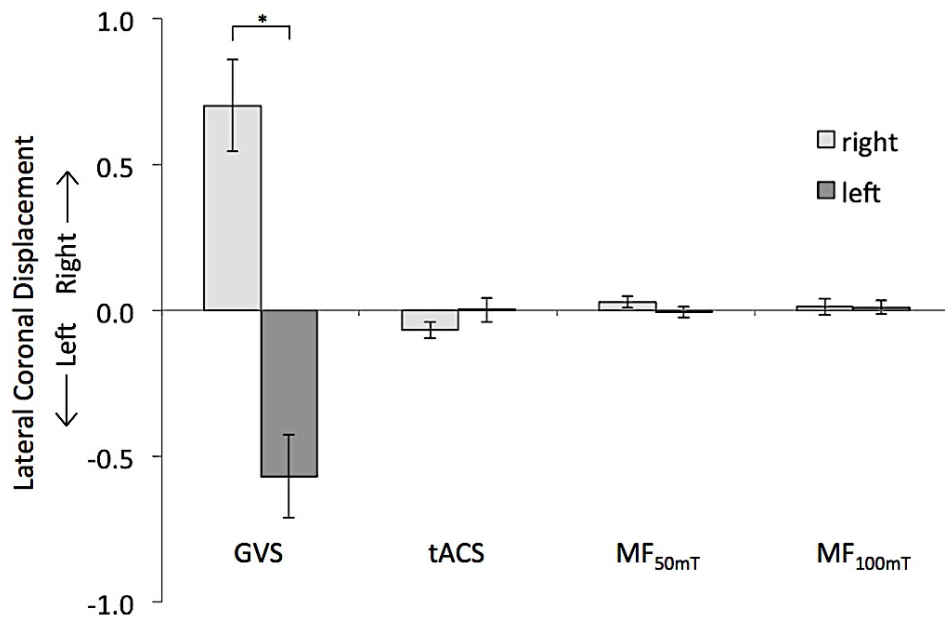


Figure 12: Effect of Side with the Lateral Coronal Displacement variable, representing all participants in each of the exposure conditions. The x-axis represents the type of exposure and the y-axis represents the lateral coronal displacement, with a negative value representing a left displacement and a positive value representing a right displacement.

Light grey bars represent a right side exposure, while dark grey bars represent a left side exposure. This graph shows the side effect being attributed to the GVS exposure, with a left side exposure showing a left coronal displacement ($-0.57\text{cm} \pm 0.14$) and a right side exposure showing a right coronal displacement ($0.70\text{cm} \pm 0.16$). This is in line with effects expected from the positive control condition.

2.3.3 Third test: Effect of experimental stimulation over Sham

In the third and final ANOVA, we pooled the different frequencies and sides of exposure for each exposure type in order to test for an overall Exposure effect. The Path Length was significantly modulated by the type of exposure ($F(4, 84) = 11.10, p < .01$, Figure 13). Post-hoc comparisons showed that the Path Length was significantly higher during GVS exposure than during Sham, tACS, MF_{50mT} and MF_{100mT} exposure and that the Path Length was also significantly higher during tACS exposure than during GVS, MF_{50mT} and MF_{100mT} exposure. Similar Exposure effects (see Table 3) were also found for Area ($F(4, 84) = 7.89, p < .05$), and Coronal Velocity ($F(4, 84) = 10.38, p < .01$).

No significant differences were found between the Sham exposure and the tACS or MF experimental stimulations.

No significant effects of Exposure were found on the Lateral Coronal Displacement and the LFB, MFB and HFB of the Coronal velocity.

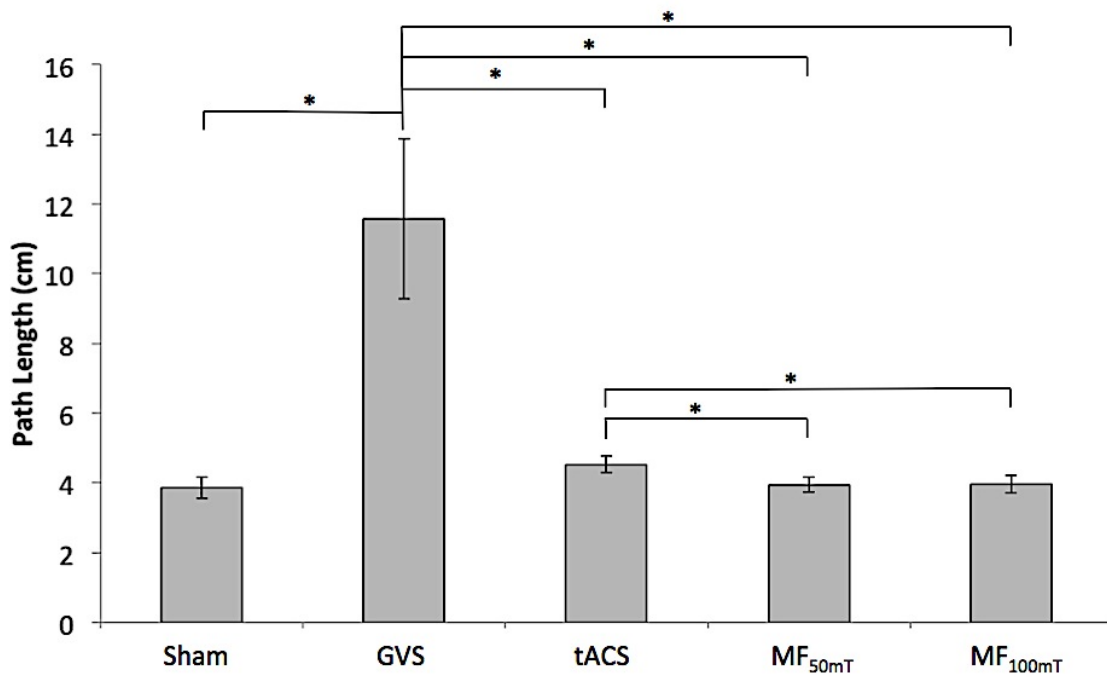


Figure 13: Path Length (average of combined frequency conditions and exposure side for all participants) in each of the exposure conditions. The GVS condition is significantly different than any other condition, showing a higher Path Length (11.57cm \pm 2.30) than Sham (3.86cm \pm 0.31), tACS (4.52am \pm 0.23), MF_{50mT} (3.94cm \pm 0.22), and MF_{100mT} (3.95cm \pm 0.25). The tACS condition also shows a significantly higher path length than the MF conditions. A higher Path Length signifies a higher destabilization.

Table 3: Mean values \pm Standard Error for the one-way ANOVA (effect of experimental stimulations) and the 2 by 4 ANOVA (effect of Side of exposure) sway characteristics. An asterisk (*) represents a significant effect ($p < .05$).

Sway Characteristic	Sham	GVS		tACS		MF _{50mT}		MF _{100mT}	
		Left	Right	Left	Right	Left	Right	Left	Right
Path Length (cm)*	3.86 \pm 0.31	11.57 \pm 2.30		4.52 \pm 0.23		3.94 \pm 0.22		3.95 \pm 0.25	
		11.52 \pm 3.09	11.62 \pm 2.59	4.31 \pm 0.25	4.72 \pm 0.29	3.98 \pm 0.24	3.90 \pm 0.22	3.99 \pm 0.23	3.92 \pm 0.29
Area (cm ²)*	0.37 \pm 0.08	4.50 \pm 1.47		0.46 \pm 0.04		0.39 \pm 0.04		0.39 \pm 0.05	
		4.55 \pm 1.95	4.45 \pm 2.10	0.42 \pm 0.05	0.50 \pm 0.05	0.39 \pm 0.04	0.39 \pm 0.05	0.39 \pm 0.04	0.40 \pm 0.07
Coronal Velocity (cm/s)*	0.47 \pm 0.05	1.75 \pm 0.39		0.59 \pm 0.04		0.50 \pm 0.03		0.51 \pm 0.03	
		1.79 \pm 0.52	1.71 \pm 0.40	0.56 \pm 0.04	0.63 \pm 0.05	0.50 \pm 0.04	0.49 \pm 0.03	0.52 \pm 0.03	0.51 \pm 0.04
Coronal Displacement (cm)*	0.01 \pm 0.04	0.07 \pm 0.08		-0.03 \pm 0.02		0.01 \pm 0.01		0.01 \pm 0.02	
		-0.57 \pm 0.14	0.70 \pm 0.16	0.00 \pm 0.04	-0.07 \pm 0.03	-0.01 \pm 0.02	0.03 \pm 0.02	0.01 \pm 0.02	0.01 \pm 0.03
Coronal Velocity LFB (%)	4.45 \pm 1.09	4.44 \pm 0.94		4.48 \pm 0.43		4.59 \pm 0.36		4.36 \pm 0.28	
		4.66 \pm 1.08	4.23 \pm 1.10	4.44 \pm 0.37	4.52 \pm 0.57	4.45 \pm 0.42	4.73 \pm 0.53	4.82 \pm 0.42	3.91 \pm 0.34
Coronal Velocity MFB (%)	4.00 \pm 0.41	4.22 \pm 0.27		4.43 \pm 0.16		4.13 \pm 0.14		4.36 \pm 0.15	
		4.12 \pm 0.31	4.32 \pm 0.41	4.45 \pm 0.17	4.41 \pm 0.20	4.01 \pm 0.15	4.25 \pm 0.18	4.36 \pm 0.20	4.37 \pm 0.18
Coronal Velocity HFB (%)	0.21 \pm 0.03	0.15 \pm 0.01		0.16 \pm 0.01		0.18 \pm 0.01		0.19 \pm 0.01	
		0.15 \pm 0.01	0.16 \pm 0.02	0.17 \pm 0.01	0.15 \pm 0.01	0.19 \pm 0.01	0.18 \pm 0.02	0.19 \pm 0.01	0.19 \pm 0.01
* signifies a significant result ($p < .05$)									

2.3.4 Head mounted device stabilization effect

Considering that the observed GVS effects were smaller than previous values reported in the literature (Yang et al., 2015), and the exposure apparatus is a unique, newly developed system not previously used in testing, an investigation of the effects of the MF exposure device on human standing balance was warranted. A short protocol was performed exploring the effects of the magnetic field exposure device on selected standing balance outcome measures (path length,

area, and coronal velocity). 11 participants each stood with their feet together and eyes closed on the force plate for four randomized repetitions, two with the MF exposure device placed on the head and two with the device off of the head. The MF exposure device itself was not turned on for any of these exposures. As represented in Figure 14, results revealed a significant decrease with the MF exposure device on compared to off for path length ($F(1, 10) = 24.56, p < .01$), area ($F(1, 10) = 21.19, p < .01$), and coronal velocity ($F(1, 10) = 30.03, p < .001$). This is evidence of a significant stabilization effect of the exposure device.

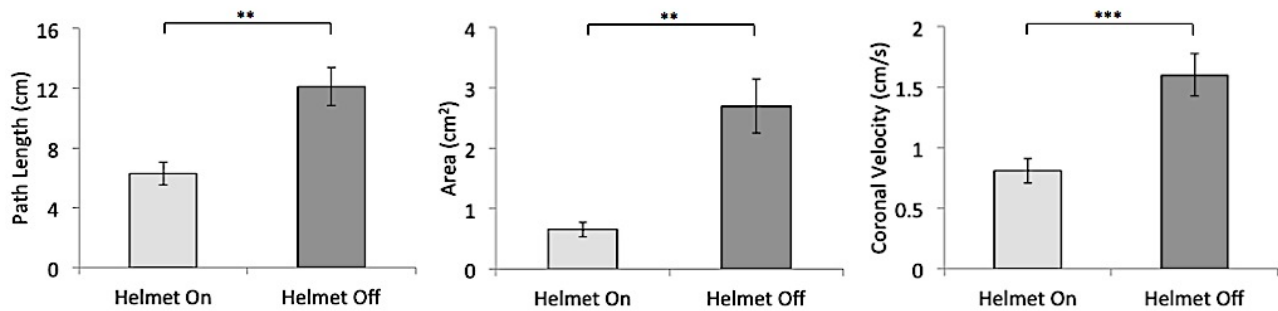


Figure 14: Graphs of selected sway characteristics revealing a significant stabilization effect with the MF exposure device on the head as compared to without in terms of Path Length (helmet on: 6.28cm ±2.54, helmet off 12.10cm ±4.25), Area (helmet on: 0.65cm² ±0.40, helmet off: 2.69cm² ±1.48), and Coronal Velocity (helmet on: 0.81cm/s ±0.34, helmet off: 1.60cm/s ±0.59). The two asterisks () indicate a significance of $p < 0.01$ and three (***) indicate a significance of $p < 0.001$.**

2.4 Discussion

This study sought to explore the effects of time-varying stimulation such as tACS and MFs on human postural control by inducing an electric field targeting the vestibular system. Our results were able to confirm the effect of a well-known direct current stimulation, GVS, on human standing balance. This is seen with an increase in Path Length, Area, and Coronal Velocity for a 5-second exposure period compared to sham. More importantly, the destabilization induced by the GVS was confirmed to depend on the side from which the stimulation occurred, as shown with the Lateral Coronal Displacement variable. These results were similar to previous findings of GVS postural control modulations (Fitzpatrick & Day, 2004; Inglis, Shupert, Hlavacka, & Horak, 1995). However, the magnitude of the response observed was greatly lower than values

reported in other studies of GVS exposure for short (< 5 s duration) exposure periods. For example, a study by Yang et al. (2015) found a peak lateral coronal displacement of 4.5 cm with a 5 s exposure to a 1 mA GVS exposure. However, our results of mean lateral coronal displacement revealed average values of only 0.6-0.7 cm (using a higher 1.5 mA exposure level). For coronal velocity, our average values were 1.8 cm/s, whereas a study by Tax et al. (2013) found average values of 2.6 cm/s, again using a lower intensity, 1 mA GVS exposure. Further investigation into this matter tested a potential stabilization effect of the MF exposure device. Analysis of the same postural sway characteristics (Path Length, Area, mean Coronal Velocity, and mean Sagittal Velocity) of 11 participants wearing the MF exposure device compared to not wearing it revealed a significant stabilization effect across all sway characteristics. This is a crucial result to be noted when interpreting observed results for the tACS and MF exposures, as subtler exposure effects may not have been exhibited due to this significant stabilization effect of the MF exposure device. Indeed, GVS produces a larger effect for a destabilized situation. For example it will produce an increased sway response with the feet together, which lessens as the feet move further apart, increasing the lateral stabilization of the participant (Day, Severac Cauquil, Bartolomei, Pastor, & Lyon, 1997; Yang et al., 2015). In this work, our efforts to augment the effect of experimental stimulation by postural destabilization through feet position (feet together), visual restriction (eyes closed), and sensorimotor impairment (foam surface on force plate) might have been counterbalanced by the stabilization effect of the MF stimulation device. This stabilization appears to result from tension on the string of the pulley system increasing the pull back to center with increased participant deviation from the COP. Results reported in this work must be discussed with this potential limit in mind.

Interestingly, tACS exposure significantly impacted Path Length, Area, and Coronal Velocity compared to the MF conditions. The observed effects can be described as a higher amounts of movement (increased destabilization) for the tACS exposures compared to the MF exposures. This significant difference between the tACS and MF exposures was unexpected considering our hypothesis that MFs have the potential to act on the human vestibular system through induced currents, thus modulating postural control. We expected that a 1.5 mA tACS exposure would induce the same current at the level of the vestibular system as a 100 mT MF. This calls into question whether the directly applied alternating current and induced MF current values at the level of the vestibular system are comparable. A study by Gandhi et al. (2001)

calculated the time-varying MF-induced current density values in the brain to be 43.9 mA/m² on average, with a peak value of 466.4 mA/m². Since these calculations were modeled based on time-varying MF sources of 0.12 and 1.6 mT at 60 Hz, it is highly likely that the MF values we used would reach much higher levels. However, modeling studies have not been done to confirm this. The current density distribution for tACS in terms of a vestibular target is also not thoroughly studied. Maximum values (closer to the stimulation electrode) were modeled to be 140 mA/m² for a 2 mA stimulus (Merlet et al., 2013). A study by Laakso et al. (2013) found that the current density was on the order of 40 mA/m² near the vestibular system, which is a value comparable to that of the MF values previously mentioned. We can also introduce the possibility that alternating current, such as that used in tACS, interact with the human vestibular system differently than the currents induced by a time-varying MF. This is probably because of different *in situ* orientations. Also, the small coil used in this protocol delivers more local induced fields and currents compared to the electric stimulation, which might also have its importance in the expression of the effect.

Another considerable difference between tACS and MF exposure comes from the way that these stimulations were administered. Indeed, the placement of the electrodes for tACS exposure directly on the mastoid process is more reliable to account for individual morphological variability compared to the adjustment of the MF exposure device to the same location on the head. The MF exposure device would need to be further adjustable to ensure that we are reaching the necessary MF exposure levels at the level of the vestibular system, as a deviation of only a few centimeters from the target source can result in a significantly diminished MF value.

In terms of the frequency domain analysis, significant effects were found only in the Coronal Velocity HFB. The main effect revealed a lower power in the HFB for tACS compared to the MF conditions. Also in the Coronal Velocity HFB, a significant Side effect, Frequency-Exposure interaction, and Exposure-Side-Frequency interaction occurred. It is difficult to interpret the meaning of these frequency domain analysis results for several reasons. First, because previous studies linking frequency domain analysis to different subsystems are based on an analysis of displacement or acceleration, not velocity (Fujimoto et al., 2014; Salsabili, Bahrpeyma, Esteki, Karimzadeh, & Ghomashchi, 2013; Taguchi, 1978). Second, our positive control failed to reach statistical significance compared to sham in the frequency domain analysis, even though it was able to demonstrate significant differences compared to Sham for all

other sway characteristics measured. This could be due to a high variability seen among the participants in their response to GVS exposure in the frequency domain analysis. It is important to note that the Side effect observed accounted for less than 1% of the variance in the data, calling to question the significance of this result. Nonetheless, a significant difference between tACS and MF exposure, exposure-frequency interactions, and Exposure-Side-Frequency interactions accounting for a higher proportion of variance in the data were found for the HFB. This has never been reported before and requires further investigation in order to determine its meaning.

With respect to the effects of tACS and MF exposure conditions compared to sham, no significant differences were found in any of the calculated sway characteristics, including the frequency domain analysis. This was unexpected for several reasons. First, in terms of MF exposure, previous research has already demonstrated that ELF MFs can impact postural control, with values as small as 0.2 mT and 1.8 mT revealing a significant stabilization effect on postural control (Legros et al., 2012; Thomas, Drost, et al., 2001; Thomas, White, et al., 2001). However, it is important to notice that these studies were reporting effects resulting from longer periods of exposure (1 hour in the Legros study as opposed to 5 seconds here). This implies that different mechanisms might be at play. In addition, the exposure device used in this study not only used much higher MF values (50 – 100 mT), but it also produced a more direct exposure to the human vestibular system due to the placement of the exposure apparatus. One possible reason that we do not see a significant stabilization effect comparable to previous studies is that our MF exposure device is capable of exposing only one side of the head at a time as opposed to delivering a whole-body exposure like the ones produced in the aforementioned experiments. It is therefore possible that the effect reported in these study is not related to a vestibular modulation, but possibly a modulation at any level of the proprioceptive or the motor loops. It is still unclear why this protocol was not capable of producing a destabilization effect like the one found previously in van Nierop et al. (2013). The best explanation for this would be the fact that our study had a much shorter MF exposure duration (5 s) compared to a 65-minute exposure duration and therefore the exposure levels we used were not high enough to be able to produce an acute (occurring within a few seconds) destabilization effect.

Another reason that the MF results are unexpected is that MFs have already been proven to induce other biological effects consistently. Time-varying MFs have reliably been known to

produce magnetophosphenes (a flickering visual perception) at MF values as low as 8-12 mT, that is suspected to be due to the influence of electric fields on retinal rod cells (Attwell, 2003; Hirata, Takano, Fujiwara, Dovan, & Kavet, 2011; Lovsund et al., 1980). Since retinal rod cells and vestibular hair cells both use graded potentials for signaling to afferent nerves, it is reasonable to conclude that sufficient levels of MF exposure should induce an effect in vestibular hair cells. All things considered, there is ample reasoning supporting the hypothesis of time-varying MFs affecting human postural control. Nonetheless, a significant effect was not reached in this particular study.

In considering the reasons as to why we have not found a significant exposure effect, we must also consider important methodological limitations. A major concern is the MF exposure device itself and the significant stabilization effect it produces. This stabilization effect, described previously, significantly diminished the effect seen in our positive control (GVS) and therefore it is probable that the device dampens any effects potentially present in the MF exposure conditions. It is most important to develop a new MF exposure device that lessens the exposure device stabilization effect, perhaps by introducing a self-supported apparatus. Furthermore, postural control is not the only way of testing vestibular system performance and it is possible that other methods of testing could reveal different results. It is noted that measurement of postural control is a credible screening test for detecting imbalance but it provides nonspecific information regarding the exact origins of imbalance (Lang & McConn Walsh, 2010). This is because postural control is not dependent solely on vestibular input, but rather a combination of visual input and other sensory input as well (Hansson, Beckman, & Hakansson, 2010). Therefore, by assessing other outcome measures, we may get a clearer view of the effects of time-varying MFs and tACS exposure on the human vestibular system. Measurements such as the Subjective Visual Vertical could be used to more specifically analyze the functioning of the vestibular system. More specifically, it can target vestibular utricle function, which is sensitive to detection of horizontal linear accelerations (Lang & McConn Walsh, 2010). Another possibility for increasing the chances of seeing an effect includes creating more instability for the participants. A study by Yang et al. (2015) exploring the effects of decreased stabilization found that GVS responses significantly decrease with improved stabilization through increased coronal stance. Therefore, it would be interesting to study the MF-induced postural control effects of a less stable position. For example standing with the feet

in tandem (heel to toe) as opposed to in the parallel position produces a less stable coronal position (L. van Nierop, 2015).

Overall, these results reveal a significant destabilization effect for GVS compared to sham in terms of a higher Path Length, Area and Coronal Velocity, and a significant lateralization effect in terms of Coronal Displacement. This confirms the effectiveness of GVS as a positive experimental control. Significant effects were found for tACS in terms of Path Length, Area, and Coronal Velocity compared to the MF conditions. Although the observed effects did not reach the significance level of the GVS exposure, it warrants the need for further investigation. This study did not reveal any significant effects of tACS and MF exposure compared to Sham, nor did it reveal any clear frequency or lateralization effects; however, these effects may be subtler under this particular experimental design due to a significant stabilization effect of the MF exposure device. Further modifications, to be discussed in the following section, must be made to the current exposure apparatus in order to properly study these effects. This study proved to be significant in further establishing GVS as a reliable method for inducing loss of balance in humans and in demonstrating a difference in the effects of tACS on human postural control compared to MF exposure, which has never been explored before. These results and future additional testing will contribute to the scientific literature informing safety exposure guidelines for live power-line workers and the general public.

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Chapter 3

3 General Conclusion

3.1 Findings, Meaning, and Applications

This research project has provided a unique experimental protocol using high MF exposure levels (up to 100 mT) that have not yet been explored before in terms of vestibular exposure. It has also been unique in testing the frequency effects of MF exposure on human standing balance. Additionally, introducing the tACS exposure to the protocol to explore its effects on standing balance has been a novel addition to the scientific literature. Therefore, this protocol is unique in several respects and has been successful in laying the groundwork for future studies involving time-varying MF and tACS exposure on human standing balance.

One limitation in the results of the study has been the finding of the significant stabilization effect of the MF exposure device. The device requires further modifications for two main purposes. First, in order to be able to more effectively expose participants directly in terms of the MF exposure more accurately targeting the vestibular system itself. This can be done with further improvement of the MF exposure device adjustment mechanism. This would be done by allowing for increased freedom of movement in different planes for the exposure coils so they can be more accurately aligned with the vestibular system of each individual. Second, in order to be able to reduce the overall stabilization effect of the exposure device so we can get a representation of postural sway that will more accurately reflect a natural movement. This would differ from the current pulley system, which introduces a pull back to center and therefore restricts movement. Future testing will be conducted after improving the MF exposure device and adjusting the sample size based on the parameters of the newly developed exposure system.

Overall, the results of this study have successfully revealed three important findings. First, the study has confirmed the effectiveness of GVS as a positive experimental control by revealing a significant destabilization effect for GVS compared to sham and a significant lateralization effect in terms of Lateral Coronal Displacement. This is an important finding, which illuminates the effectiveness of our experimental protocol as well as some of its discrepancies. Second, the study has found differences in tACS exposure compared to time-varying MF exposure, which has never been found previously. Although the observed effects did

not reach the level of the GVS exposure, it warrants the need for further investigation in order to clarify the meaning of this finding. For example, differences in tACS and MF exposure reactions could be due to protocol discrepancies in the placements of the electrodes compared to the placements of the MF exposure coils, which would call for further adjustment of the experimental protocol. Differences could also be explained due to the induced currents of the MFs being different to those produced by tACS. This would require further investigation into the distribution of these fields through modeling work. Third, the study has revealed some interesting frequency interactions with exposure type and side of exposure in the Lateral Coronal Displacement and Coronal Velocity HFB variable, warranting the need for further investigation. This is a significant discovery, leading to the need for further exploration into frequency interactions and different frequency effects based on exposure type and side of exposure. The problem with interpreting the frequency band analysis results is the lack of studies performing frequency band analysis on Lateral Coronal Velocity. A protocol using different frequency band analysis techniques could be beneficial for targeting these effects. For example, increasing the exposure duration would allow for an improved frequency domain analysis using coronal displacement. This can be more accurately compared to other research studies in its domain.

Although this study did not reveal any significant effects of tACS and MF exposure compared to Sham, nor did it reveal any clear frequency or lateralization effects, these effects may be subtler under this particular experimental design due to the significant stabilization effect of the MF exposure device, as previously mentioned. It is clear that further modifications must be made to the current exposure apparatus in order to properly study these effects. Indeed, all results reported in this work had to be discussed with potential bias of the MF exposure apparatus in mind. Therefore, removal of this bias is essential in order to move forward with future studies.

Considering the applications of this study, we can note the significance of completing this important pilot work in order to lay the groundwork for future testing. By allowing the identification of unforeseen experimental limits, this work pushes to consider alternative experimental methods. It is important to note that in this study, MF exposure levels that were used are much higher than the average levels of exposure experienced by power line workers and the general public. However, because the thresholds tested correspond to the experimental bases used by guideline agencies to establish their recommendations (after applying an uncertainty

factor and a safety factor), this study constitutes useful literature from this perspective. Because these threshold effects are suspected to result from magnetic induction processes, the tACS condition is important in considering that: first, it allows for testing of the effects of a directly applied alternating current to the vestibular system and second, it allows for a comparison to its magnetically induced equivalent. This is a useful comparison allowing for further exploration of the potential differential impacts of directly applied currents vs. induced currents on postural control. Mainly, this study has been crucial in determining the next step for future studies to be performed in the lab in order to further explore MF and tACS effects on human standing balance.

3.2 Future Studies

Overall, this study proved to be significant in further establishing GVS as a reliable method for inducing loss of balance in humans, in demonstrating a difference in the effects of tACS on human postural control compared to MF exposure, and in demonstrating the possibility of exposure-frequency interactions, which have never been explored before. Forward steps will introduce the possibility of different testing methods in order to assess vestibular performance in response to MF and tACS exposure.

The introduction of different outcome measures can be used, as opposed to standing balance, in order to assess vestibular functioning. One such test is using a Caloric Reflex Test, which specifically tests for the functioning of the VOR through stimulation of the horizontal semicircular canal. This test would therefore be useful for specifically testing an individual component of the vestibular system instead of the system as a whole. This can further be used for investigation of mechanisms of action. Another test that can be used is the Subjective Visual Vertical test, which is a measure of what participants perceive to be the vertical direction compared to the real life vertical. This is another test of the VOR and can be used to test specifically for functioning of the utricle. Videonystagmography is a third variable can be used to test for the functioning of the VOR. Videonystagmography simply uses an infrared video camera to track eye movements, with nystagmus signifying vestibular disturbance. The aforementioned tests all target the VOR, however recording of EMG activity could be used to determine the contribution of the VSR upon exposure to MFs and tACS. These tests would be able to more accurately target vestibular responses compared to postural control, an outcome that is not solely based on vestibular input.

Before further testing takes place, consideration must also be made in terms of the MF exposure system itself. The current system uses a pulley-like device, which allows for head movement, but also shows a significant stabilization effect on the participant. A proposed improvement to this device would be to have the MF coils placed on a moveable support system that is capable of rolling from side to side. This would solve the problem of the stabilization effect caused by the pull of the string in the pulley system, while still allowing for free participant movement on the force plate. Another consideration to be made is the placement of the MF exposure coils with respect to the participants' head. Measures should be taken in future protocols that allow for more adjustment of the MF exposure coils so that they can be placed to more accurately target the vestibular system with respect to different participants.

Other things to consider in future testing include the use of more participants, using the data from this study to calculate a specific n-size. Since this current study was a pilot and since a significant stabilization effect was found early in the study, the n-size was low. Testing more participants in the future could yield significant results. Future studies will also take into account a possible threshold effect for MF exposure. For example, the study protocol could include exposing the participant to different flux density values. For instance, using values from 0-100 mT in increments of 10 mT at a single frequency could help determine the flux density threshold at which a response is more likely to occur. This can also be explored with tACS using different levels of current intensities.

With these future initiatives and protocol adjustments in mind, further progress can be made in terms of understanding the effects of MF and tACS exposure on human standing balance. Overall, the results of this study and future additional testing will contribute to the scientific literature informing safety exposure guidelines for live power-line workers and the general public. New knowledge in this domain have a potential strong impact in terms of translational applications, which could apply to clinical developments related to vestibular disorders.

Appendices

Appendix A: Health Science Research Ethics Board Approval.



Research Ethics

Western University Health Science Research Ethics Board HSREB Full Board Initial Approval Notice

Principal Investigator: Dr. Alexandre Legros
Department & Institution: Schulich School of Medicine and Dentistry\Medical Biophysics, Lawson Health Research Institute

HSREB File Number: 106122

Study Title: Impact of extremely low-frequency (<300Hz) magnetic fields (up to 100 mT) on postural control in humans
Sponsor:

HSREB Initial Approval Date: March 02, 2015
HSREB Expiry Date: March 02, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Other	Appendix 1 Phone Questionnaire	2014/12/02
Western University Protocol		2015/01/01
Advertisement	Appendix 2 - Advertisement	2015/01/01
Letter of Information & Consent	Appendix 3 - Letter of Information and Consent Form	2015/01/01
Instruments	Appendix 4 - Field Status Questionnaire	2015/01/01

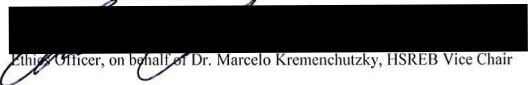
The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review. If an Updated Approval Notice is required prior to the HSREB Expiry Date, the Principal Investigator is responsible for completing and submitting an HSREB Updated Approval Form in a timely fashion.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.


Ethics Officer, on behalf of Dr. Marcelo Kremenutzky, HSREB Vice Chair

Ethics Officer to Contact for Further Information

Erika Basile	Grace Kelly	Mina Mekhail	Vikki Tran
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Western University, Research, Support Services Bldg., Rm. 5150

www.uwo.ca/research/services/ethics

**Western University Health Science Research Ethics Board
HSREB Annual Continuing Ethics Approval Notice****Date:** February 27, 2016**Principal Investigator:** Dr. Alexandre Legros**Department & Institution:** Schulich School of Medicine and Dentistry\Medical Biophysics, Lawson Health Research Institute**Review Type:** Full Board**HSREB File Number:** 106122**Study Title:** Impact of extremely low-frequency (< 300Hz) magnetic fields (up to 100 mT) on postural control in humans**HSREB Renewal Due Date & HSREB Expiry Date:**

Renewal Due -2017/02/28

Expiry Date -2017/03/02

The Western University Health Science Research Ethics Board (HSREB) has reviewed the Continuing Ethics Review (CER) Form and is re-issuing approval for the above noted study.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice (ICH E6 R1), the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.



Ethics Officer, on behalf of Dr. Joseph Gilbert, HSREB Chair

Ethics Officer to Contact for Further Information: Erika Basile ___ Katelyn Harris ___ Nicole Kaniki ☒ Grace Kelly ___ Vikki Tran ___

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**Western University Health Science Research Ethics Board
HSREB Amendment Approval Notice**

Principal Investigator: Dr. Alexandre Legros

Department & Institution: Schulich School of Medicine and Dentistry\Medical Biophysics, Lawson Health Research Institute

Review Type: Full Board

HSREB File Number: 106122

Study Title: Impact of extremely low-frequency (< 300Hz) magnetic fields (up to 100 mT) on postural control in humans

HSREB Amendment Approval Date: February 09, 2016

HSREB Expiry Date: March 02, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version	Date
Revised Western Protocol	Received Oct 8, 2015		


The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the amendment to the above named study, as of the HSREB Initial Approval Date noted above.

HSREB approval for this study remains valid until the HSREB Expiry Date noted above, conditional to timely submission and acceptance of HSREB Continuing Ethics Review.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice Practices (ICH E6 R1), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.


Ethics Officer, on behalf of Dr. Marcelo Kremenchutzky, HSREB Vice Chair

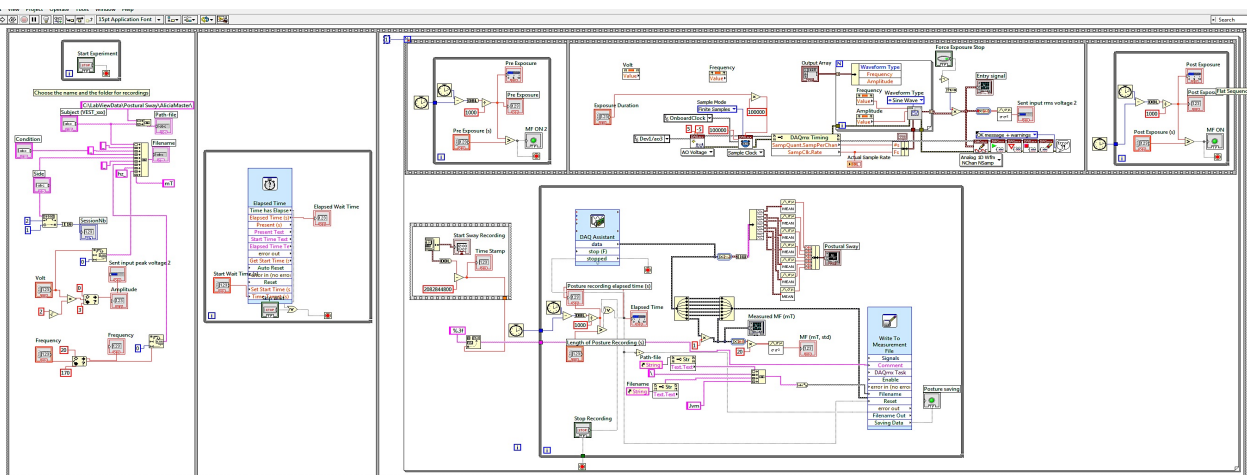
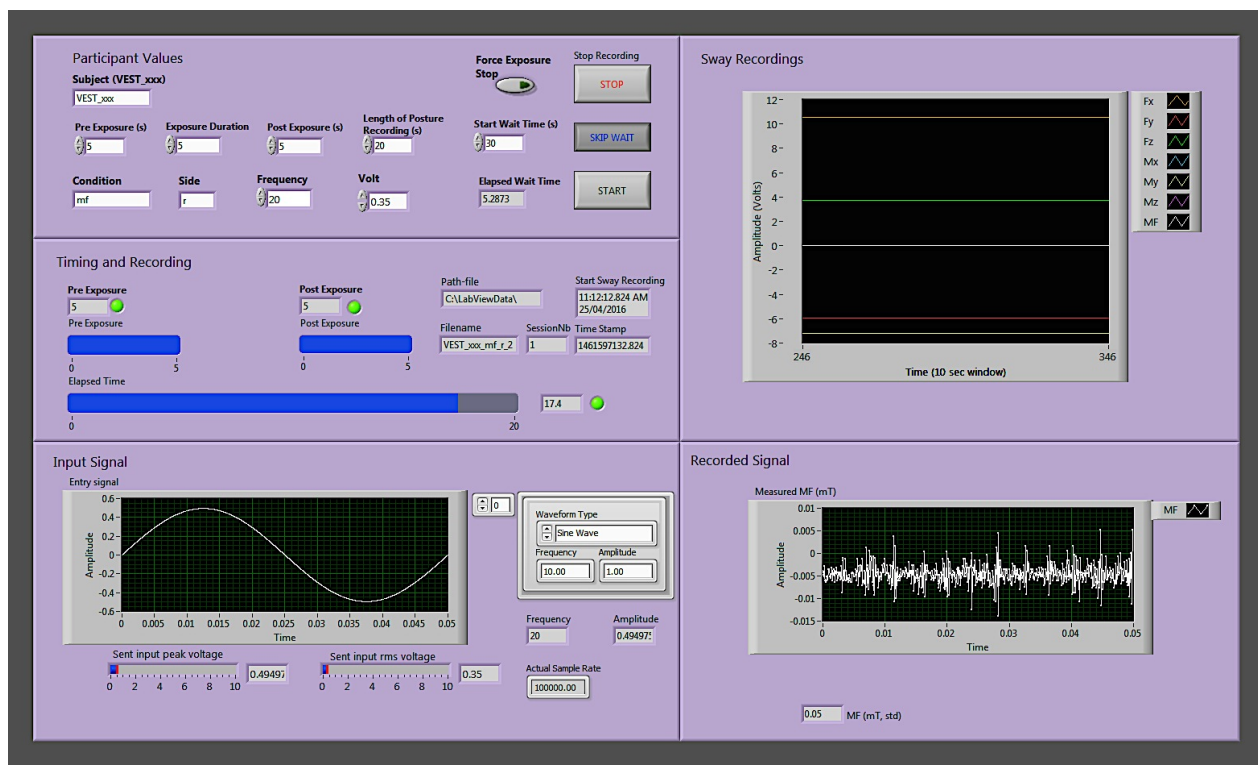
Ethics Officer to Contact for Further Information: Erika Basile ☒ Katelyn Harris ☐ Nicole Kaniki ☐ Grace Kelly ☐ Vikki Tran ☐

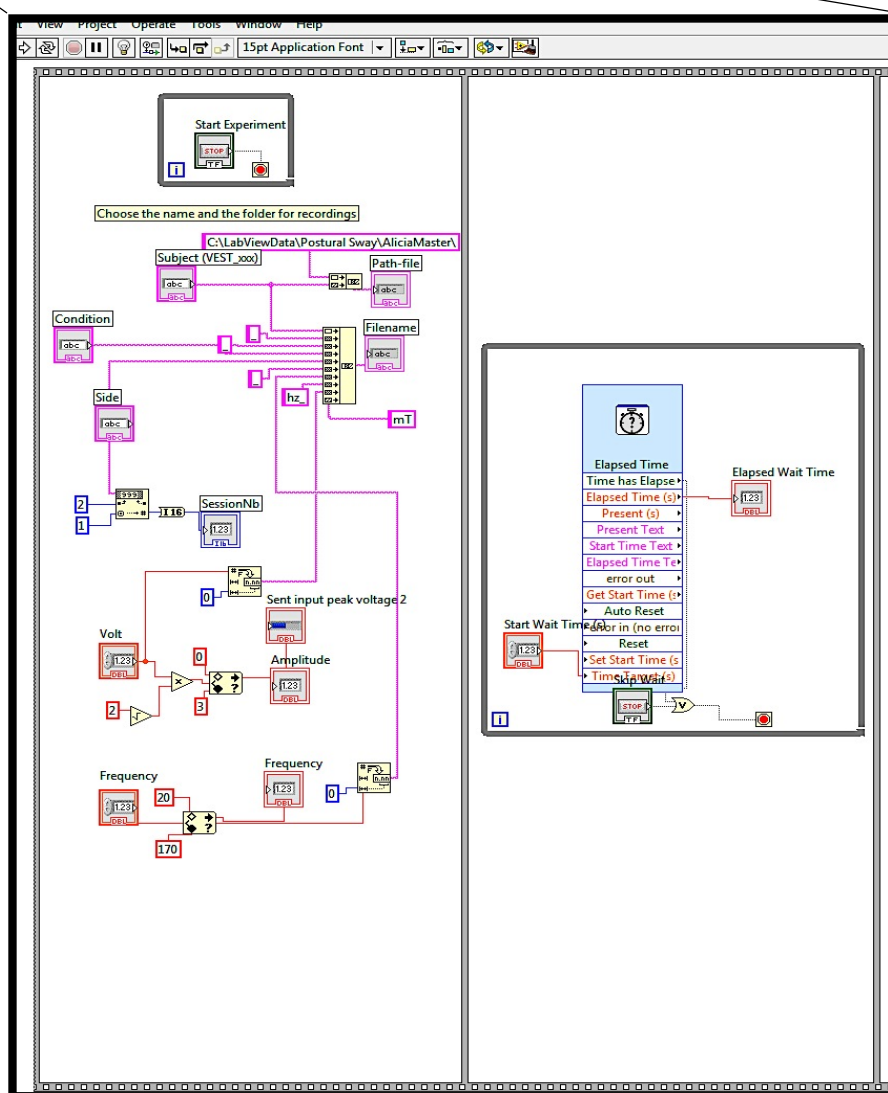
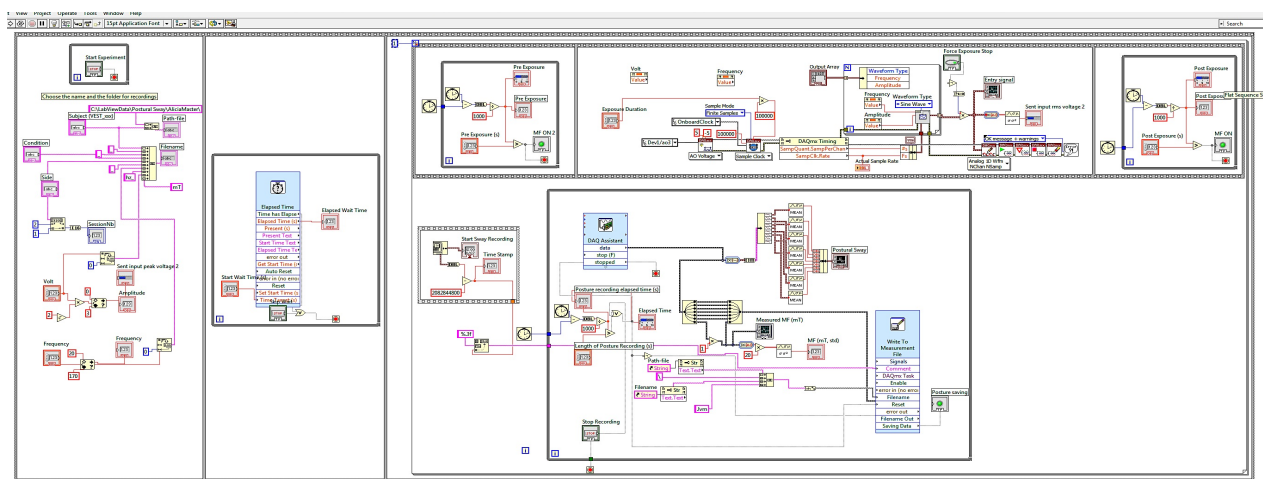
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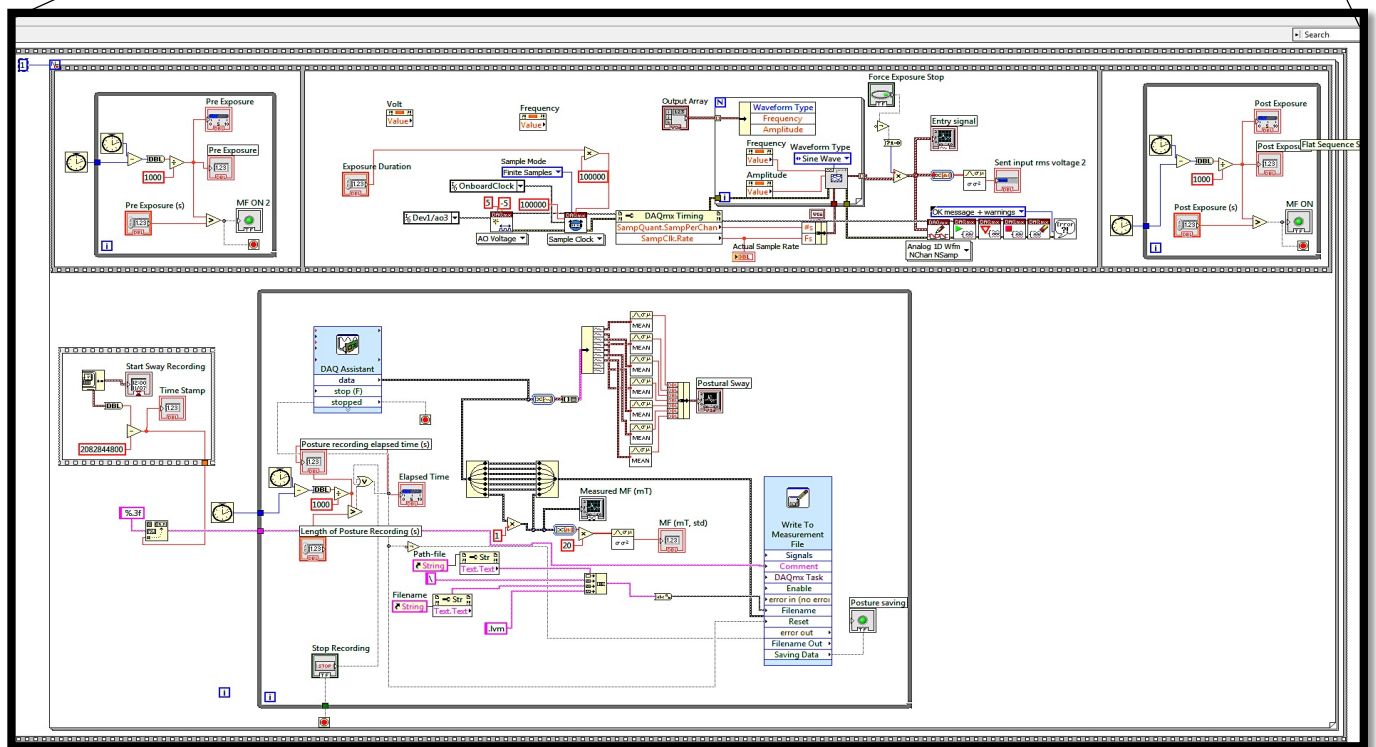
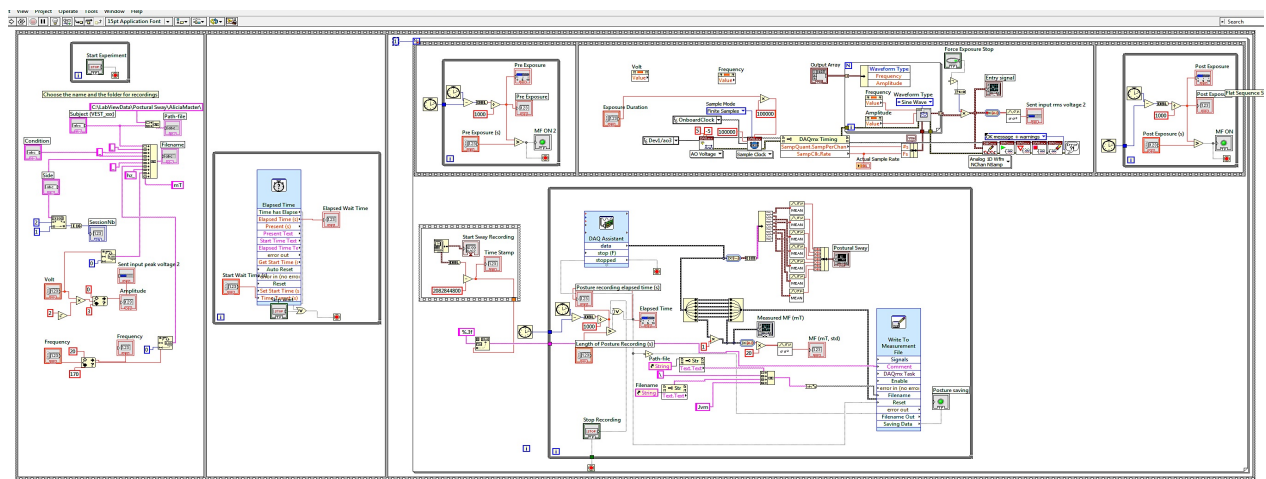
Appendix B: All participant characteristics (n=22) taking part in the postural control study.

	Sex	Dominant Hand	Weight (lbs.)	Height (cm)	Age
1	Male	Right	168	190	38
2	Female	Right	95	147	21
3	Male	Right	151	174	24
4	Male	Right	167	178	23
5	Female	Right	111	155	23
6	Male	Right	190	188	21
7	Male	Right	160	175	35
8	Female	Right	154	160	25
9	Male	Right	194	181	21
10	Female	Right	124	170	22
11	Male	Right	198	183	20
12	Male	Right	171	183	20
13	Male	Left	230	184	24
14	Male	Right	185	185	24
15	Female	Right	95	152	18
16	Female	Right	105	158	20
17	Female	Left	120	168	18
18	Male	Right	160	180	22
19	Female	Right	110	158	21
20	Female	Right	120	165	21
21	Male	Right	145	170	26
22	Female	Right	155	173	20
n = 22	F=10 M=12	R=20 L=2	150.4 ± 36.8	171.7 ± 12.4	23.1 ± 4.9

Appendix C: LabView Data Collection Program.







Appendix D: MatLab Program with Sway Calculations.

```

1 clear;
2
3 clc;
4 readfolder='/Users/aliciaallen/Desktop/Masters_Stuff/data/VEST_Data/participant_data/';
5
6 participant={'004' '005' '006' '007' '008' '009' '010' '011' '012' '013' '014' '015' '016' '017' '018' '019' '020' '021' '022' '023' '024' '025'};
7 condition={'sham' 'tdcs' 'tacs' 'mf'};
8 side={'l' 'r'};
9 frequency={'20' '60' '90' '120' '160'};
10 intensity={'0' '1'};
11
12 %% Constant
13
14 sr = 10000; %sampling rate
15 expo_time = 5*sr; %5s pre, during, and post exposure duration
16
17 %calibration and sensitivity matrices from platform manual
18 C = [ 1.518 0.01 -0.012 0.001 0.001 -0.004;
19       -0.001 1.518 -0.004 0.01 0.01 -0.005;
20       -0.014 0.008 5.913 -0.009 0.01 -0.019;
21       0.001 0 0 0.59 -0.002 0.004;
22       0 0.001 0 -0.001 0.588 0.002;
23       0 0.004 -0.002 0 0.002 0.305];
24
25 %filtering out moment and force
26 lowcut = 10; %cutoff frequency (filter out MF frequencies)
27
28
29 %% experimental protocol
30 for NoPar=1:size(participant,2)
31     Col=0;
32     for NoCond=4%1:4
33         for NoSide=2%1:2
34             for NoFreq=2:5
35                 for NoInt=2%1:2
36                     %% Name creation
37                     if NoCond==1
38                         SHAM=true;
39                         fname = ['VEST_' char(participant(NoPar)) '/' 'VEST_' char(participant(NoPar)) '_' char(condition(NoCond)) '_n_0hz_0mT.lvm'];
40                         ColName = [char(participant(NoPar)) '_' char(condition(NoCond))];
41                     elseif NoCond==2
42                         SHAM=false;
43                         TDCS=true;
44                         fname = ['VEST_' char(participant(NoPar)) '/' 'VEST_' char(participant(NoPar)) '_' char(condition(NoCond)) '_' char(side(NoSide))
45                                 '_0hz_0mT.txt'];
46                         ColName = [char(participant(NoPar)) '_' char(condition(NoCond)) '_' char(side(NoSide))];
47                     elseif NoCond==3
48                         TDCS=false;
49                         TACS=true;
50                         fname = ['VEST_' char(participant(NoPar)) '/' 'VEST_' char(participant(NoPar)) '_' char(condition(NoCond)) '_' char(side(NoSide))
51                                 '_' char(frequency(NoFreq)) 'hz_0mT.txt'];
52                         ColName = [char(participant(NoPar)) '_' char(condition(NoCond)) '_' char(side(NoSide)) '_' char(frequency(NoFreq))];
53                     else
54                         TACS=false;
55                         fname = ['VEST_' char(participant(NoPar)) '/' 'VEST_' char(participant(NoPar)) '_' char(condition(NoCond)) '_' char(side(NoSide))
56                                 '_' char(frequency(NoFreq)) 'hz_' char(intensity(NoInt)) 'mT.lvm'];
57                         ColName = [char(participant(NoPar)) '_' char(condition(NoCond)) '_' char(side(NoSide)) '_' char(frequency(NoFreq)) 'hz_'
58                                 char(intensity(NoInt))];
59                     end
60                 end
61             end
62         end

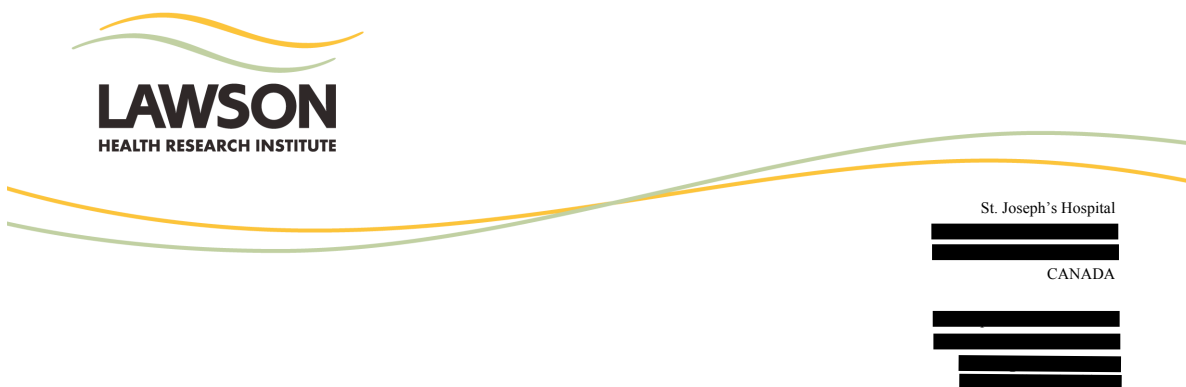
```

```

62
63 %% Read file and defining exposure period
64 disp(fname)
65 data=importdata([readfolder fname]);
66
67 if NoCond == 1
68     ramp = 0; %if magnetic field no ramp
69     start=115;
70     MFdata=data(115:(115+150000),8);
71 elseif NoCond == 4
72     ramp = 0; %if magnetic field no ramp
73     start=115;
74     MFdata=data(115:(115+150000),8);
75 else
76     ramp = 1*sr; %duration of ramp (1s for tacs/tdcs, 0s for MF)
77     %ramp = 0;
78     sway_recording_start = data(1,9);
79     stimulation_start = (data(1,10))/1000; % convert starstim time stamp to s.
80     start = ((stimulation_start - sway_recording_start)*sr)-expo_time;
81 end
82
83 stime=3*expo_time+2*ramp;
84 ending = start+stime;
85 start=single(start);
86 ending=single(ending);
87
88
89 %% Forceplate to COP
90 T = data(1:stime+1,1); %time reset to 0;
91
92 FMraw = [data(start:ending,2) data(start:ending,3) data(start:ending,4) data(start:ending,5) data(start:ending,6) data(start:ending,7)];
93 clear data;
94
95 %calibration multiplied by the outputs
96 Cfm = C*FMraw';
97 Cmy = Cfm(5,:);
98 Cmx = Cfm(4,:);
99 Cfz = Cfm(3,:);
100 Cfzt = Cfz';
101
102 %calculation of the inputs
103 X = -Cmy./Cfz; %based on AMTI manual computation
104 Y = Cmx./Cfz;
105
106 %filtering
107 X=lowpass(X,sr,lowcut);
108 Y=lowpass(Y,sr,lowcut);
109
110 Y=-Y; %because subject is facing the back of the forceplate
111 X=X*100;Y=Y*100; %convert from m to cm
112
113
114 %% Exposition Periods
115 %defines the pre, during, and post exposition periods
116 pre = expo_time;
117 expo_on = pre+ramp;
118 expo_off = expo_on+expo_time;
119 post = expo_off+ramp;
120 end_cut = post+expo_time;
121
122 Before = 1:pre;
123 During = expo_on:expo_off-1;
124 After = post:end_cut-1;
125
126 BeforeV = 1:pre-1; %for time domain of sway velocity graph to match index lengths
127 DuringV = expo_on:expo_off-2;
128 AfterV = post:end_cut-2;
129
130
131 %% COP Variables
132
133 % sway characteristics for during exposition period
134 MXD=X(During)-mean(X(Before));
135 PathDuring = sqrt(diff(X(During)).^2+diff(Y(During)).^2);
136 kDuring = convhull(X(During),Y(During));
137 VelXDuring = diff(X(During))*sr;
138
139 % sway characteristics for each column of data
140 Pathlength(NoPar,Col)=sum(PathDuring);
141 Area(NoPar,Col) = polyarea(X(During(kDuring)),Y(During(kDuring)));
142 MeanVelX(NoPar,Col)=mean(abs(VelXDuring));
143 mMXD(NoPar,Col)=mean(MXD);
144
145 % frequency domain analysis
146 % pwelch parameters
147 window = 49999;
148 overlap = window/2;
149 lo = lowcut;
150 hi = 0;
151
152 %pwelch for coronal X velocity
153 [xspecc_vel_during,f] = pwelch (VelXDuring-mean(VelXDuring), window, overlap, window, sr);
154
155 idx10Hz = find (abs(f-10)==min(abs(f-10)));% find frequency closest to 10Hz
156 idxF0_10 = 1:idx10Hz;
157
158 %normalization and arrangement of results into columns
159 NormalizeFreqX_During = xspecc_vel_during(idxF0_10)./sum(xspecc_vel_during(idxF0_10));
160 VarNormSpec = ['NormSpectrumX' ColName(5:end)];
161 cmd=[VarNormSpec '(NoPar,:)=NormalizeFreqX_During;'];
162 eval(cmd);
163
164
165 %% breaking loops
166 if SHAM||TDCS||TACS break, end
167 end
168 if SHAM||TDCS break,end
169 end
170 if SHAM break, end
171 end
172 end
173 end
174

```

Appendix E: Letter of Information and Consent Form.



LETTER OF INFORMATION

Investigators: Dr. Alexandre Legros, Imaging, Lawson Health Research Institute
Dr. Julien Modolo, Imaging, Lawson Health Research Institute
Alicia Allen (MSc Candidate), Western University

Place of Research: Room F5-112
Lawson Health Research Institute
St. Joseph's Health Centre
[REDACTED]
London, Ontario

Impact of extremely low-frequency (<300Hz) magnetic fields (up to 100 mT) on postural control in humans

Study Rationale

Electrical currents like those in power-lines and in household appliances produce magnetic fields in their surroundings. These magnetic fields change direction 60 times in a second in North America, 50 times in Europe: they are said to have a frequency of 60 or 50 Hertz (60 Hz – 50 Hz), and are often referred to as power-line frequency magnetic fields. The strength of a magnetic field is measured in milliTesla (mT). For example, the strength of the magnetic field in an MRI is usually 1,500 or 3,000 mT, but research MRI systems can go up to 11,000 mT.

Changing magnetic fields have the ability to create small electrical currents in the human body. Stronger magnetic fields create stronger currents. Everyone is exposed to power-line frequency magnetic fields on a daily basis. This is the reason why possible effects of magnetic fields on humans should be studied. This current study is aiming to use magnetic fields at different frequencies and strengths: 20, 60, 120, and 160 Hz with strength from 0 to 100 mT.

VERSION: JAN 2015

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LAWSON HEALTH RESEARCH INSTITUTE

Initials: _____
Page 1 of 5

Purpose of the Study

You are invited to participate in a study looking at the possible effects of magnetic field exposure on postural control. Postural control is your body's ability to be in an upright position. This study will eventually test 80 volunteers.

Procedures

If you agree to participate in this study, you will take part in one experimental session after signing the consent form. This session will last 2 hours and will involve magnetic field exposure. During this session, the first 15 minutes will be designated to reading the letter of information and consent and informing you about the study. You will then be given the opportunity to have all your questions about the study answered. After you have signed the consent form, formally agreeing to take part in the study, we will begin the experimental procedure.

You will first be fitted with the magnetic field exposure system, which resembles large headphones (like in figure 1). For the next 75 minutes of the experiment, there will be several short 10-second periods where you may or may not be exposed to a magnetic field. During these periods, you will be standing with your eyes closed on a force plate (like the one in figure 2), feet 2-3 inches apart. You will have rest periods of 30 seconds between the 10-second intervals, at which point you will be allowed to sit in a chair (to avoid prolonged periods of standing). 5 seconds before each exposure period starts an audio tone will sound, signalling you to stand again. Periodic rests will also take place at regular 15-minute intervals.



Figure 1: Diagram of the magnetic field exposure system.



Figure 2: Diagram of the force plate you will stand on during the study.

Next, the MF exposure system will be removed and you will be fitted with another device (called a galvanic stimulation device), which is a cap that will be fitted on your head. This involves taping two electrodes just behind your ears. This portion of the experiment will be similar to the first in that you might be exposed to a magnetic field while standing on a force plate and each exposure will last 10 seconds with a 30 second rest in between (where again you will be permitted to sit). The total time for this portion will be 7 minutes. Finally a third sequence will be given using the same exposure device as in the previous condition, lasting another 7 minutes.

The total magnetic field exposure time for this experiment will be 22 minutes. During the entire protocol, you will not be aware of whether the magnetic field is generated or how strong it will be. After the experiment, you will be asked to complete a magnetic field detection survey.

When you will have completed the experiment, you will be reimbursed for expenses such as travel and time spent in the study session. If the experiment is not fully completed, reimbursement will still be provided (see reimbursement section).

During this experiment, you will be exposed to a time-varying magnetic field (varying between 0 and 160 times per second) from 0 to 100 mT. The strength of the exposure will be much lower than what you would experience in a Magnetic Resonance Imaging (MRI) scanner. You may experience some side effects during the experiment such as nausea or slight discomfort/tingling or pain where the electrodes are placed. There is also a risk of falling during the experiment, since postural control may be compensated.

Participation in this study requires that you refrain from alcohol, caffeine or nicotine consumption 24 hours prior to the experiment, and until the end of the experiment. If you usually drink coffee on a regular basis, then this abstinence may eventually induce headaches. Furthermore, if you are a regular or occasional smoker, you may experience, anxiety, depressive feelings or impulsive behaviour caused by nicotine deprivation during 24 hours.

Qualified representatives of the following organizations may look at your medical/clinical study records at the site where these records are held, for quality assurance (to check that the information collected for the study is correct and follows proper laws and guidelines). Examples include: Representatives of Lawson Quality Assurance Education Program

Reimbursement

You will be given a forfaitary reimbursement of \$50 to cover for your expenses associated with the participation to this study (including for example bus, taxi car costs, parking costs, meal if travelling from far). Would you have to withdraw from the experiment for any reason, you would still receive this forfaitary reimbursement whether or not you complete the experiment.

Inclusion criteria

You must be healthy and be between 18 and 55 years old.

Exclusion criteria

You should not take part if you have a limitation of movement, if you have ever experienced an epileptic seizure, if you suffer from chronic illness (e.g., diabetes, psychiatric or severe cardiovascular or neurological diseases), if you have a condition that impacts your stability or balance, if you have a vestibular system disorder, if you have a history of head or eye injury involving metal fragments, if you have ever worked in a metal shop or been a soldier, if you have some type of implanted electrical device (such as a cardiac or cerebral pacemaker), if you are wearing metal braces on your teeth, if you have a permanent piercing, if you use illicit drugs regularly, if you could be pregnant, or if you have an intrauterine device. Additionally, those who are hypertensive or who take medication for hypertension are not eligible to participate. Moreover, you will be asked to not smoke or have caffeinated or alcoholic beverages in the 24 hours preceding your participation to the study.

Risks

Participant Frustration: This study requires you to be alert and focused for the 2-hour duration of the experiment. While we attempt to provide you with the most comfortable experience possible, repeated sitting and standing may become irritating or tiring for some participants. If you experience difficulties to fulfil these criteria, you may withdraw from the study.

Power-line frequency magnetic fields: There are no known risks of exposure to power-line frequency magnetic fields at the level and duration you will be exposed in this study (up to 100 mT). Indeed, both the International Commission on Non Ionizing Radiation Protection (ICNIRP, 2010) and the World Health Organization (WHO, 2007) have conducted exhaustive review of the scientific literature on the topic and concluded the absence of health effects to power-line frequency magnetic field exposure at those levels.

Galvanic and tACS Stimulation: This is considered to be a very safe method of stimulation at the level for which we are using it (2 mA). Galvanic stimulation involves applying a weak direct current to the vestibular system. The level of induced electric fields at the level of brain tissue that is much lower (<1 mV/m) than other modalities, such as transcranial magnetic stimulation (TMS), which can reach levels up to several hundreds of V/m. However, you might experience mild and transient side effects such as: mild or moderate sensations of pain on the skin under the anode, general discomfort,

mild vertigo, eyestrain, blurred vision, head fullness and difficulty concentrating, light itching and tingling beneath the electrodes, mild headache, and burning sensation. All aforementioned side effects are transient.

All experimental conditions: Since the vestibular system (responsible for maintaining balance) is being investigated, there is potentially a risk for losing your balance during the testing conditions. However, this risk disappears as soon as you open your eyes and move your feet to re-equilibrate yourself (Fitzpatrick and Day, 2004; Van Nierop, 2013).

Benefits

You will receive no direct benefits as a result of your participation in this study.

Withdrawal

Participation in this study is completely voluntary. You may refuse to participate, refuse to answer questions or withdraw from the study at any time with no affect on your employment or academic status.

Confidentiality

The information collected from you will include your name, date of birth and phone number, this enables us to validate your age and contact you. All information will be kept strictly confidential. You will be given a code number so that no names will be used in recorded data. The consent form with the name and the code number will be kept in a locked file cabinet. All results from the study will be kept confidential and any publication of this research study will be in grouped form with no reference to individual names. Storage of the postural sway data will be performed electronically. This electronic folder will be stored on a computer with updated antivirus and firewalls of Room E5-112 (with a locking door) at Lawson Health Research Institute. Only staff has the key to the door and only members of the research team have the password for the computer. Representatives of The University of Western Ontario Health Sciences Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of this research.

Further Information

You will be given a copy of this “Letter of Information” to keep for your records.

You do not waive any legal rights by signing the consent form.

If you have any questions or you would like to further discuss any aspect of the study, please do not hesitate to contact Alexandre Legros (Ph.D., Associate Professor, Bioelectromagnetics Scientist, Principal Investigator, LHRI) at [REDACTED]

If you have any questions about the conduct of this study or your rights as a research participant you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute [REDACTED]

Consent to participate in the study entitled:

Impact of extremely low-frequency (<300Hz) magnetic fields (up to 100 mT) on postural control in humans

I, _____, have read the Letter of Information, have had the nature of the study explained to me, and I agree to participate. All questions have been answered to my satisfaction.

I accept to be contacted in the future for a potential participation to a forthcoming study

(circle your answer): YES NO

DATE

SIGNATURE

PRINTED NAME OF PERSON OBTAINING CONSENT

SIGNATURE OF PERSON OBTAINING CONSENT

VOLUNTEERS NEEDED

Healthy volunteers needed to participate in a study investigating the effects of magnetic fields on balance

(Impact of extremely low-frequency (<300Hz) magnetic fields (up to 100 mT) on
postural control in humans)

Those between the ages of 18 and 55 inclusive are eligible to participate.

You are invited to participate in a study that will test your standing balance in response to magnetic field exposure. During this study you will be asked to stand for short intervals while balance is recorded. You should not take part if you have a limitation of movement, if you have ever experienced an epileptic seizure, if you suffer from chronic illness (e.g., diabetes, psychiatric or severe cardiovascular or neurological diseases), if you have a condition that impacts your stability or balance, if you have a vestibular system disorder, if you have a history of head or eye injury involving metal fragments, if you have ever worked in a metal shop or been a soldier, if you have some type of implanted electrical device (such as a cardiac or cerebral pacemaker), if you are wearing metal braces on your teeth, if you have a permanent piercing, if you use illicit drugs regularly, if you could be pregnant, or if you have an intrauterine device.



Western

For more information please contact (e-mail preferred):

Dr. Alexandre Legros
Medical Biophysics, Western University

<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>	<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>	<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>	<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>	<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>	<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>	<p>Postural Sway and Power-Line Magnetic Fields Dr. Alexandre Legros</p>
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Appendix G: Phone Questionnaire.

Phone Questionnaire

To participate in this study, you must be between the ages of 18 and 55 inclusive.
To determine whether or not you are a potential candidate for this study, we would ask you to answer the following questions:

1. Do you currently suffer from a chronic illness that requires that you regularly take medication(s)? Yes No
If yes, which one(s)?
2. Do you suffer from any condition that impacts your stability or balance? Yes No
If yes, please explain.....
3. Have you ever suffered from a vestibular system disorder? Yes No
4. Are you currently experiencing any inner ear problems (such as infection)? Yes No
5. Have you ever had an epileptic seizure? Yes No
6. Do you wear a neural or cardiac pacemaker, or do you have a metal implant in your head or chest? Yes No
7. Do you have any permanent piercing? Yes No
8. Are you wearing a hearing aid system? Yes No
9. Do you regularly use drugs? Yes No
10. Do you smoke? Yes No
11. The experiment requires that you not be under the influence of tobacco, alcohol, coffee or tea during the test. Is it impossible for you to abstain from smoking, consuming alcohol or drinking caffeinated beverages for 24 hours before the experiment ? Yes No
12. Do you have the possibility to be driven back home after the experiment? Yes No
13. Dominant hand :
14. Date of birth :
15. Weight : Height :

Identification number:

NOTE: This information will be used to ensure you are meeting the study's inclusion criteria, and to categorize the data when analyzed. If you sign the consent form, the information you provide on this questionnaire will be kept, locked and stored for seven years and then shredded and/or mulched using a standard hospital protocol for document destruction (even in the event you withdraw from the study before having completed it). Should you discontinue participation in this study prior to signing the consent for, the information you provide on this questionnaire will be instantaneously discarded.

Identification information

✂

Last Name: First name:

Address:

City:

Home phone number: Work:

E-mail address:

Sex: Date of birth:

Identification number: (To be filled out by a member of the research team)

Curriculum Vitae

Name:	Alicia Allen
Post-secondary Education and Degrees:	Western University London, Ontario, Canada 2014-present M.Sc. Candidate Western University London, Ontario, Canada 2008-2013 B.H.Sc.
Honours and Awards:	Deans Honours List 2010-2011, 2011-2012, 2012-2013 Internal Research Fund Competition Lawson Health Research Institute \$15,000 2015-2016
Related Work Experience:	Teaching Assistant (KIN 2271B Physical Activity and Health) The University of Western Ontario 2014-2015 Research Assistant Lawson Health Research Institute 2013-2016

Peer Reviewed Articles

In prep.	Allen A., Villard S., Modolo J., Thomas A. W., Legros A. A Literature Review: The Effects of Power Line Frequency Magnetic Fields on the Human Vestibular System, in preparation. Allen A., Villard S., Thomas A. W., Legros A. Impact of Extremely Low-Frequency (<300 Hz) Magnetic Fields (up to 100 mT) on Human Postural Control, Bioelectromagnetics, in preparation.
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Conference Proceedings (and Presentations)

- 2016 Allen A., Villard S., Corbacio M., Goulet D., Plante M., Souques M., Deschamps F., Ostiguy G., Lambrozo J., Thomas A. W., Legros A. Impact of electromagnetic fields on human vestibular system and standing balance: pilot results and future developments. *IOP Conference Series: Materials Science and Engineering*, Volume 120 (1), 2016
- Allen A., Villard S., Corbacio M., Goulet D., Plante M., Souques M., Deschamps F., Ostiguy G., Lambrozo J., Thomas A. W., Legros A. Acute impact of extremely low frequency (< 300 Hz) magnetic fields up to 100 mT on human postural control (platform). *Annual Joint Meeting of the Bioelectromagnetics Society and the European Bioelectromagnetics Association - BioEM2016*, Ghent, Belgium, June 5th - 10th 2016
- Villard S., Allen A., Corbacio M., Goulet D., Plante M., Souques M., Deschamps F., Ostiguy G., Lambrozo J., Thomas A. W., **Legros A.** Effect of time-varying magnetic fields on the vestibular function. *Annual Joint Meeting of the Bioelectromagnetics Society and the European BioElectromagnetics Association – BioEm2016*, Ghent, Belgium, June 5th -10th, 2016
- 2015 Allen A., Modolo J., Corbacio M., Goulet D., Plante M., Souques M., Deschamps F., Ostiguy G., Lambrozo J., Thomas A. W., **Legros A.** Impact of Electromagnetic Fields on Human Vestibular System and Standing Balance: Pilot Results and Future Developments. *Proceeding: IEEE Radio and Antenna Days of the Indian Ocean (RADIO)*, Mauritius, September 21st - 24th 2015, doi: 10.1109/RADIO.2015.7323406
- Allen A., Modolo J., Corbacio M., Goulet D., Plante M., Souques M., Deschamps F., Ostiguy G., Lambrozo J., Thomas A. W., **Legros A.** The impact of extremely low frequency (< 300 Hz) magnetic fields (up to 100 mT) on human standing balance. *Proceeding: Annual Joint Meeting of the Bioelectromagnetics Society and the European Bioelectromagnetics Association - BioEM2015*, Asilomar, US, June 14th - 19th 2015

Conference Peer Reviewed Abstracts (and Presentations)

- Allen A., Villard S., Corbacio M., Goulet D., Plante M., Souques M., Deschamps F., Ostiguy G., Lambrozo J., Thomas A. W., Legros A. Acute impact of time-varying magnetic fields on human postural control: pilot results and future developments. London Health Research Day, London, Ontario, Canada, March 29th 2016
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